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Analysis of NYDEC guidelines for extended detention basins: Effectiveness in water quality improvement in western and central New York

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ANALYSIS OF NYDEC GUIDELINES

FOR EXTENDED DETENTION BASINS: EFFECTIVENESS

IN WATER QUALITY IMPROVEMENT IN WESTERN AND CENTRAL NEW YORK

by

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NOMENCLATURE

TSS	Total Suspended Solids
C_V	Runoff Coefficient
V	Precipitation Volume
I	Precipitation Intensity
D	Precipitation Duration
Δ	Precipitation Interval
CV_V	Coefficient of Variation of Volume
CV_Q	Coefficient of Variation of Intensity or Flow Rate
CV_D	Coefficient of Variation of Duration
NYDEC	New York Department of Conservation
WQA	Water Quality Act
EPA	Environmental Protection Agency
NPDES	National Pollutant Discharge Elimination System
BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
NURP	National Urban Runoff Program
NTIS	National Technical Information Service
VR	Runoff Volume
Q	Peak Flow-Through Rate
R	Fraction of Initial Solids Removed
v_s	Settling Velocity of Particles
A	Surface Area of the Detention Basin
h	Average depth of basin

V_B	Volume of basin
n	Turbulence or short circuiting constant that is used to indicate settling performance
k	v_s/h (sedimentation rate coefficient)
t	V/Q (residence time)
R_L	Long term average fraction of TSS removed for variable runoff flow entering a detention basin
R_M	fraction removed at mean runoff rate
r	$1/CV_q2$
CV_q	coefficient of variation of runoff flow rates
Z	maximum fraction removed at very low rates
Ω	Emptying of discharge rate of basin
V_E	Effective volume of basin
$K_{0,1}$	modified Bessel function of the second kind
ν	volume of rain which fills the basin
M	the mean bypassed load per storm
M_R	total runoff load
r_1	$1/CV_q^2$ and $r_2 = 1/CV_d^2$
CV_q	coefficient of variation of runoff flow rates
CV_d	coefficient of variation of runoff durations
q	storm runoff flow rate
Δ	average interval between storm midpoints
V	basin effective volume, divided by mean storm runoff volume (V_E/V_R)
f_v	fraction of all volumes NOT captured by basin
$1-f_v$	% of sediment removed

f_Q fraction NOT removed under quiescent conditions

f_D fraction NOT removed under dynamic conditions

OAR_Q Overall average sediment removal under quiescent conditions

OAR_D Overall average sediment removal under dynamic conditions

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ABSTRACT

The New York State Department of Environmental Conservation (NYDEC) has recently issued guidelines for stormwater management. One widely utilized management practice is the extended detention basin wherein improved water quality is achieved through sedimentation. NYDEC recommends these be designed so that the volume of storm runoff detained is equivalent to the first flush, defined as the first ½" of runoff or runoff from a 1-year, 24 hour storm event, whichever is greater, from all land areas for which the perviousness has been changed. It also suggests a minimum detention time of 24 hours. This thesis establishes if these generic criteria, generally adopted from studies in the Metropolitan Washington, D.C. area, are sufficient for the central and western New York state region. A computer model is developed to implement an existing technique to analyze the removal of particulate pollutants through sedimentation. The model uses local meteorological data, watershed characteristics and detention basin geometry as input. The results of the analysis, applied to a case study, show that a basin properly designed to the NYDEC guidelines is effective in providing water quality improvement. For the case study basin, an average of 86.4% of the suspended particulate pollutants were removed. It is, however, critical that the NYDEC specifications regarding storage volume are followed or the basin will not provide effective removal of suspended particulate pollutants.

ACKNOWLEDGEMENTS

The successful completion of this work could only have been accomplished with the help and continued support of my thesis advisor, Frank Sciremammano. In addition to assistance on my thesis, Dr. Sciremammano made it possible to pursue this study in urban stormwater quality, in the environmental engineering area of study, by arranging additional classes and study beyond the set mechanical engineering curriculum. Also, thanks to Charles Haines, mechanical engineering department head, for allowing me to complete a thesis in an area slightly outside the realm of conventional mechanical engineering. And finally, thanks to my husband, Kim, for his support and prodding.

1.0 INTRODUCTION

1.1 STORMWATER RUNOFF

Stormwater runoff can be defined as the portion of precipitation which flows over the land surface, ultimately reaching a water body. Figure 1.1, illustrating the hydrologic cycle, is helpful in understanding the process of stormwater runoff. Runoff generated by precipitation has three components:[12]

- Surface Runoff - a residual of precipitation after accounting for all losses. The losses include depression storage and ponding, infiltration, and evapotranspiration from the earth's surface. The subtraction of these losses from precipitation will yield excess or net precipitation which becomes surface runoff.

- Interflow - is that portion of water infiltrating into the soil zone which moves in a horizontal direction, due to lower permeability of subsoils, and eventually reaches a surface water body. The amount of interflow is again residual from infiltration after subtraction of the groundwater recharge, soil moisture storage, and evapotranspiration from soil and vegetation cover.

- Groundwater Runoff (base flow) - is defined as that part of precipitation which infiltrates through the soil profile to replenish groundwater. Most stream flows during prolonged drought periods are sustained by groundwater runoff. That portion of stream flow sustained by groundwater runoff is considered the base flow.

Stormwater runoff is a natural process and left unimpeded by human intervention produces a natural landscape through

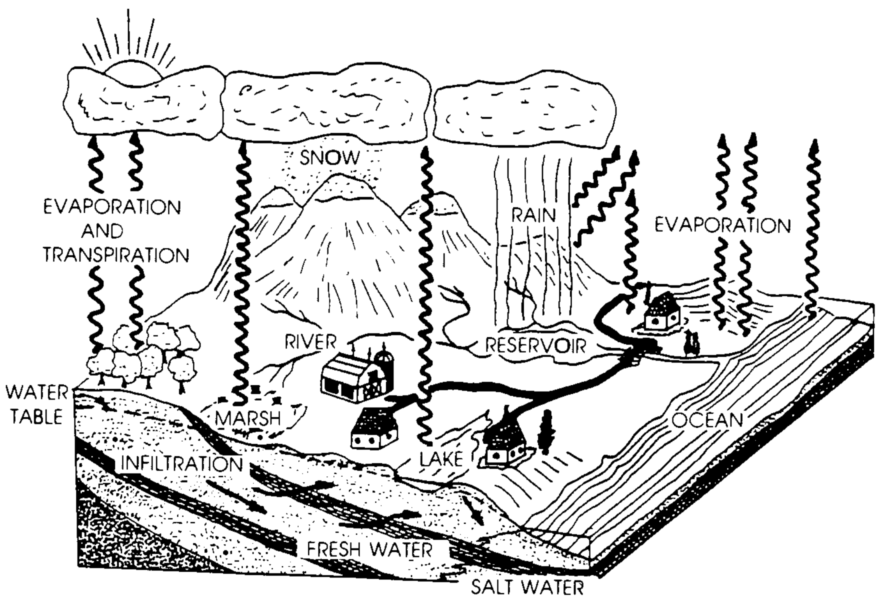


Figure 1.1: **The Hydrologic Cycle [12, pg.3]**

centuries of time. However, as humans urbanize and develop previously untouched land the nature of stormwater runoff changes drastically. As more land becomes covered by impervious surfaces, such as roads, buildings and parking lots, stormwater is prevented from percolating into the soil. Instead, it drains directly and rapidly to the nearest waterbody. This creates several problems. The first is the increase in flow, both in terms of volume and peak rate, which can result in more frequent, more severe flooding and accelerated erosion. The soil particles transported in the stormwater due to erosion can be deposited as sediment in the receiving waterbodies and can adversely impact fish and wildlife habitat. The increased runoff also reduces the amount of water available for groundwater recharge causing a reduction in the base flow available to streams and other waterbodies, again often to the detriment of aquatic life.[12]

In addition to the problems associated with increased runoff volume mentioned above, contaminants transported via runoff also create additional problems. In urban areas, paved and rooftop surfaces collect pollutants from airborne deposition or human activity. These pollutants would normally infiltrate the soil profile where physical and biological processes remove them. For impervious surfaces they are instead flushed to surface waters during storms. This can be significant as illustrated by the Environmental Protection Agency calculation that "runoff from the first hour of a moderate-to-heavy storm in a typical U.S. city will contribute more pollution load than would the city's untreated sanitary sewage during the same period of time."[12]

1.2 STORMWATER MANAGEMENT

It is clear that stormwater management is an important issue, but what exactly is stormwater management? The NYDEC [12] defines stormwater management in two parts. One part is quantitative control. This is accomplished by using a system of vegetative and structural measures which are used to control the increased volume and rate of surface runoff caused by man-made changes to the land. The second part is qualitative control using a system of vegetative and structural measures to control pollutants carried by stormwater runoff. The overall goal, again as defined by the NYDEC [12] is as follows: "The quantity and quality of stormwater run-off from any specific development should not be substantially altered from pre-development conditions."

1.3 MANAGEMENT METHODS

Urban stormwater management has historically focused on managing the quantity of water released from the developed watershed into streams, lakes and other waterbodies. There are, therefore, many measures in place to predict and control peak stormwater flow rates. A few of these practices are worth defining at this point. One method is infiltration. Infiltration may be achieved through use of a basin, pit, trench, or impoundment where stormwater runoff is collected for temporary storage so as to allow it to seep into the soil profile.[12]

Another method is retention. Retention refers to a practice wherein stormwater runoff is temporarily stored by collection in a permanent pool of water; the only release being by evaporation or partial infiltration or by overflow when the basin's designed storage volume is exceeded.[12] A retention pond is also known as a wet pond.

The final method, to be discussed here, is detention which is widely utilized in new developments. There are two different types of basins used to detain stormwater runoff: peak shaving detention and extended detention basins. A peak shaving detention basin is designed to store stormwater runoff by collection in a temporary pool of water and released at a slower rate. The main objective of a peak shaving detention basin is the reduction of the peak rate of discharge of storm runoff achieved through storage and gradual release. By contrast, an extended detention basin is designed to maintain runoff in storage for an extended period of time, usually 24 hours or greater.[12] Due to longer detention time, extended detention basins must provide more storage volume. Figure 1.2 shows a typical extended detention basin. Peak shaving and, to a lesser extent, extended detention basins have long been used for flood protection as they are very effective at retarding runoff and reducing flow rates to limit flood damage to downstream areas.

Several of the above mentioned practices for managing urban stormwater runoff can also be useful in water quality

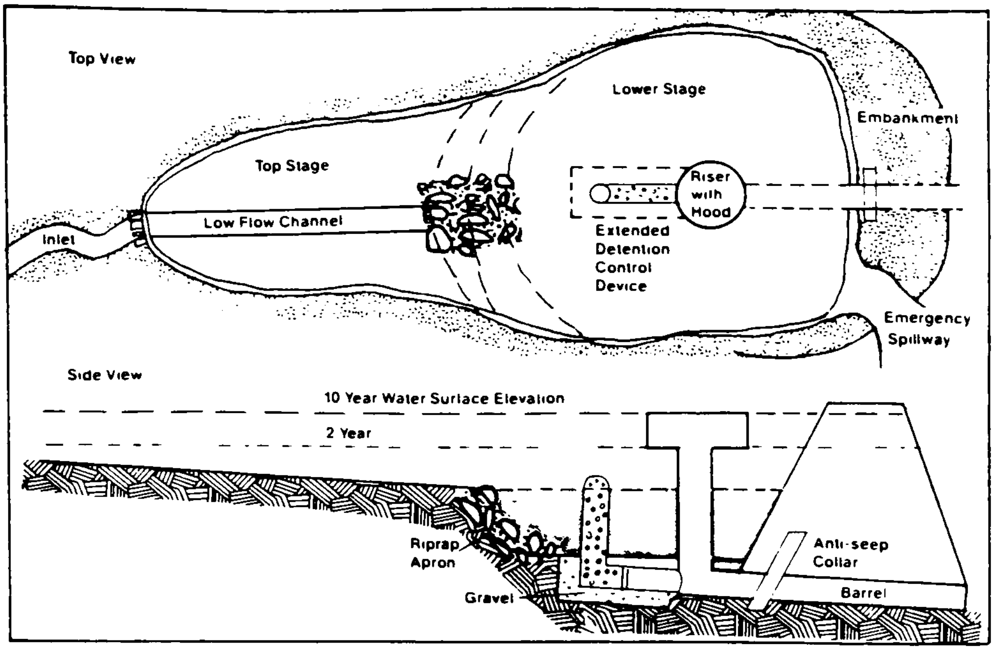


Figure 1.2: **Schematic of Extended Detention Pond** [12, pg. 121]

management. Infiltration removes pollutants through biological and physical processes as the water seeps into the soil. A retention or wet pond removes pollutants through gravity settling of particulates and biological uptake by pond vegetation. In an extended detention basin, the extended residence time of the stormwater runoff in the basin allows for more effective settling and removal of particulates. Extended detention basins are the focus of this study and will hereafter be referred to as detention basins for simplicity.

Recently there has been an increased emphasis on the quality of the runoff from urban watersheds. Two issues have influenced the shift in focus from quantity to a broader focus on quantity and quality. The first is the increasing awareness of the public regarding the environment. In the past, pollution from point sources, such as industrial plant waste, were the major contributors to the degradation of receiving waters; these are now regulated and controlled. Pollution from non-point sources is generally not. However, non-point source pollution is now recognized as a major cause of the water quality problems in the nation's receiving waters.[2] The second factor is the passing of the Water Quality Act of 1987 (WQA). The WQA requires the Environmental Protection Agency (EPA) to develop a National Pollutant Discharge Elimination System (NPDES) permit program in order to address urban stormwater pollutants. [20] Contaminates such as suspended solids, phosphorus, nitrates, hydrocarbons and others are potential pollutants from untreated urban stormwater.

Pollutants in urban runoff originate from human activity as well as natural processes. Hydrocarbons from automobiles accumulate on streets and parking lots, deposition of airborne pollutants occurs on all surfaces, fertilizers and pesticides are applied to lawns and construction activity leaves land open to soil erosion; all of which add pollutants to stormwater. Natural processes such as decomposition of organic matter and wind and water erosion similarly cause pollutants to be transported by storm runoff. The EPA [23] has categorized urban runoff into seven general categories as outlined in Table 1.1.

TABLE 1.1: CONTAMINANTS IN URBAN RUNOFF

CONTAMINANTS IN URBAN RUNOFF
Floatables and visual contaminants
Degradable organics
Suspended solids
Nutrients
Bacteria, Virus
Toxicants
Dissolved solids

Each of the above contaminant categories can contribute to water quality problems.

This thesis will concentrate on techniques and design criteria used to reduce stormwater impacts on water quality through removal of suspended solids. Suspended solids may themselves cause a variety of problems such as unacceptable aesthetic conditions and the formation of sediment deposits. Such deposits may smother bottom dwelling aquatic organisms, impede navigation and restrict river flows. Organic sediment can also react to form biochemical oxygen demand.[23] In addition to these inherent impacts, other contaminates such as nitrates, phosphorus and heavy metals will adhere to suspended solids. These contaminates can also be extremely harmful to aquatic life in receiving waters.

One of the most effective means of eliminating suspended particulates from stormwater is through gravity settling, the removal of particles through sedimentation. The removal rate of particles is directly related to the size of the basin, the detention time, and the size of the particles. Chemical flocculation also helps to eliminate suspended solids as the heavier flocculent particles overtake and coalesce with small, lighter solids.[12] These heavier, larger solids settle more readily. Dissolved pollutants can be removed via other mechanisms, such as biological uptake. These processes are, however, beyond the scope of this thesis.

Most peak shaving detention basins have short detention times, thus, not allowing the suspended solids to settle out of the water. For water quality improvement, it is important that detention basin design allows the water to remain in the basin long enough for sedimentation be effective.

The New York State Department of Environmental Conservation (NYDEC) has recently published some generic guidelines to help in achieving improved stormwater quality.[12] The guidelines for extended detention state that the volume of runoff detained should be equivalent to the runoff volume produced by the "first flush". The "first flush" is defined as the larger of the following: the first ½ inch of runoff or runoff from a 1-year, 24 hour storm. The runoff should also remain in an extended detention basin for a minimum of 24 hours to allow for sedimentation to occur.[12] As outlined in the following literature review, much research has been done in support of these generic guidelines. However, most of this research was conducted in the Washington D.C. and Maryland regions. The objective of this thesis is to establish if these generic criteria are sufficient for the central and western New York state region.

This objective will be accomplished through the following steps:

1. Rainfall statistics will be calculated from long term local (i.e. Rochester, NY) meteorological data and applied to a specific watershed.
2. An existing technique will be implemented through a computer program which will take as input this local rainfall data, watershed characteristics and

detention basin geometry and output the percent removal of TSS through sedimentation.

3. This percent removal is used to evaluate the functioning of a detention basin designed using the NYDEC guidelines.

2.0 LITERATURE REVIEW

Much has been written on the subject of urban stormwater quality. One of the earlier works in this area was done by the Northern Virginia Planning District Commission [13] for the Metropolitan Washington Council of Governments. A guidebook was prepared which summarizes "best management practice" (BMP) efficiency estimates intended for use in evaluating urban non-point pollution management strategies. One section of the guide deals directly with detention basin BMP's. Detention basins in the metropolitan Washington region were characterized in order to define the existing non-point pollution management benefits. Twelve months of hourly runoff data from the Washington Metropolitan region were used in order to obtain statistics for a year of "average" wetness, needed for the analysis. Modifications to standard detention design were then suggested in order to increase the solids settling process in order to remove sediment and suspended pollutant loadings. An investigation of extended detention times revealed that an average detention time on the order of 24 hours, which equates to a brim-full drawdown time of approximately 40 hours, would remove particles as small as fine silts.

Some time later the Metropolitan Washington Council of Governments [16] published a more comprehensive manual on controlling urban runoff based on the above cited publication [13]. This work talks extensively about the benefits of solids reduction in stormwater through the use of extended detention times, stating that if stormwater is detained for 24 hours or more, as much as 90% removal of particulate pollutants is possible. It is of import to note that both this work [16] and the above cited work [13] were based on precipitation and runoff data for the Washington metropolitan area.

The New York State Department of Environmental Conservation (NYDEC) has published some broad guidelines for the design of extended detention basins for improved water quality.[12] Much of the background work for this is drawn from the earlier studies in the Washington D.C. area [13 & 16]. The NYDEC suggests that the volume detained should be equivalent to the first flush, defined by the DEC as the first ½ inch of runoff or runoff from a one-year, twenty four hour storm event, whichever is greater. They also suggest that the minimum detention time should be twenty four hours, excepting smaller runoff events (.1-.2 inches) which should be detained a minimum of 6 hours. An emergency spillway should also be provided for a 100 year, 24 hour storm event and pond outfall velocities should be less than or equal to 4 ft/s during 2 year storm events. A critical aspect in the definition of detention time should be documented at this point. The Washington D.C. region studies [13 & 16] state the detention time should be an average of 24 hours, which equates to a brim-full drawdown time of approximately 40 hours. The NYDEC [12] states the detention time should be a minimum of 24 hours. Interpretation of 24 hours as a total drawdown time would result in an average residence significantly less than 24 hours which may result in reduced suspended pollutant removal rates.

The previously cited works were all based on data from a limited geographical area. Of import to this thesis is the effect local meteorological data may have on the reduction in particulate pollution in extended detention basins. Roesner, Burgess and Aldrich [15] emphasized the selection of the design storm as an important factor in the management of urban runoff quality. They examined six U.S. cities in areas with widely varying climatic conditions and found that most rainfall occurs during small storms. This is significant to water quality control as the majority of pollutants are transported at the beginning of a storm or during the first flush. Several small storms will therefore convey more contaminants than a large storm covering the same time period. Hydrologic simulations using long-term rainfall records of these areas indicated that a reasonable design storm was on the order of the 1-month to 4-month storm and a unit storage volume of .2 to .9 inches of runoff provided effective pollutant capture. This strategy of capturing small storms is typically in direct contrast to detention basins designed to control peak flow since the later concentrate on large storms for flood control.

Urbonas, Guo and Tucker [20] point out the need for rational, scientifically based methods to size urban stormwater runoff facilities in order to enhance runoff water quality. The authors emphasize the importance of using actual rainfall statistics. The design method they develop utilizes rainstorm records as its base instead of a synthesized design storm. Runoff volumes were obtained for the period under investigation by converting rain point diagrams to runoff volume point diagrams. This method assumes an empty basin for each new storm event and is therefore not completely applicable to extended detention ponds. However, their method revealed that the performance in removing settleable pollutants can be upgraded by implementing some simple design guidelines based upon local meteorological data.

Latimer, Mills, Hoffman and Quinn, [9] also analyzed the effectiveness of water quality improvement through the use particulate pollutant settling. They analyzed the removal of suspended solids via an extended detention basin after a spring and summer storm. The differences in the removal of suspended solids was significant, again pointing to the need to use actual rainfall statistics in order to obtain accurate water quality improvement projections. If rainfall/runoff variations are accounted for, they state that detention ponds, with relatively low construction and maintenance costs, are an economical way to treat urban runoff.

The work by Grizzard, Randall, Weand, and Ellis [5] has proved pivotal in the area of water quality, particularly with respect to sedimentation processes, and is the basis for many works on extended detention. Grizzard and his colleagues conducted field and laboratory studies of the performance of detention facilities for the removal of selected pollutants from urban stormwater. The laboratory studies consisted of the measurement of pollutant concentration reductions for stormwaters of low, moderate, and high initial suspended solids, through quiescent settling in plexiglass columns. Field studies, in the Washington metropolitan area, were then conducted on a full scale detention pond which was retrofit with a restricted release structure to increase the residence time of the average storm event. Both laboratory and field results supported an average detention time of 24 hours with a drawdown time (time required to empty basin) of 40 hours for a brim full condition.

A publication by the Maryland Department of The Environment, Sediment and Stormwater Administration [10] support Grizzard's [5] conclusions. The Maryland publication recommends an average detention time of 24 hours based on the settling behavior of urban pollutants. Laboratory studies which achieve ideal settling conditions indicate that 60 to 70 percent of urban sediments and attached pollutants settle out within the first six hours and the remaining sediment requires as much as two days. They also state that the actual settling performance of wet ponds typically require a 24 hour period to remove the bulk of sediments. Since ideal settling conditions rarely occur in field conditions, an average detention time of 24 hours is recommended for design.

Akan [2] presents a design aid to size detention basins and outlet facilities for removal of particulate pollutants from storm runoff. This method used a single design event approach with the main objective being to detain the stormwater runoff for a period of time long enough to settle out the particulate. A mean detention time of 18 hours was stated as being adequate to settle out 60% of total suspended solids, lead and hydrocarbons and 45% of the total biochemical oxygen demand (BOD), copper and phosphates. Given the design storm, detention time and evacuation time, the pond can then be sized accordingly.

The EPA [4] published a manual outlining a method for estimating urban runoff quality through the use of detention basins. It states that detention and retention basins are the most effective and reliable of several techniques examined for control of urban runoff pollutant loads; the principal mechanism of removal being sedimentation. A detention device is obviously of a fixed size and capacity whereas storm runoff is highly variable. The performance of any detention device should, therefore, be characterized in such a way as to account for the variability and intermittent nature of storm runoff. The methodology used by the EPA is based on a probabilistic technique that accounts for this variability. The basic objective is to provide a basis for establishing "first order" design specifications in terms of goals for long-term average removal of urban runoff pollutants. The theory is based upon DiToro and Small's publications on stormwater treatment, interception and storage.[3,17] Stahre and Urbonas, both pioneers in the area of stormwater runoff quality, use the EPA method in analyzing estimated runoff quality in a given detention basin.[18]

DiToro and Small [3] present a framework and analysis of the performance of stormwater control devices that capture and store runoff and is the basis of the EPA method [4] outlined above. Based on the variability of the runoff characteristics from storm to storm, it is generally acknowledged that initial assessment studies should focus on the long-term rainfall-runoff process rather than a particular storm event.

Also used in the EPA method [4], Small and DiToro [17] present a statistical method of analysis that estimates long-term treatment efficiencies based on the size of the device, the removal efficiency relationship (performance rating curve) of the device, and the statistical properties of the runoff. The results from this type of analysis are particularly useful for preliminary evaluations of a detention design before more time and money is invested in sophisticated simulation.

The above cited works are in no way an exhaustive summary of the literature published on the topic of urban water quality enhancement via extended detention basins. Instead, they provide the background necessary for the calculations and discussion in this thesis.

3.0 THEORY

3.1 STORM RUNOFF PROCESS, INTERCEPTION AND STORAGE

The storm runoff process can be characterized as a series of independent events occurring randomly in time, as shown in Figure 3.1.[23] The intrastorm variability, depicted in figure 3.1(a), is ignored and each event is characterized by its duration (D), runoff volume (V_R), time between storms (Δ) and the average runoff flow ($Q = V_R/D$).

For each storm event, it is assumed that the storage device, in this case a detention basin, intercepts a constant flow rate (Q_I), figure 3.1(c), and the basin captures a fixed volume, namely the basin volume (V_B), as shown in figure 3.1(d). The unshaded areas in figure 3.1(e) represent the uncaptured or overflow volume.

Due to the inherent variable nature of rainfall, outlined above, storm runoff volumes vary. However, stormwater control devices, such as detention basins, only provide a fixed storage volume. This allows for a fixed runoff flow to be treated during any storm event; treatment performance will therefore fluctuate.

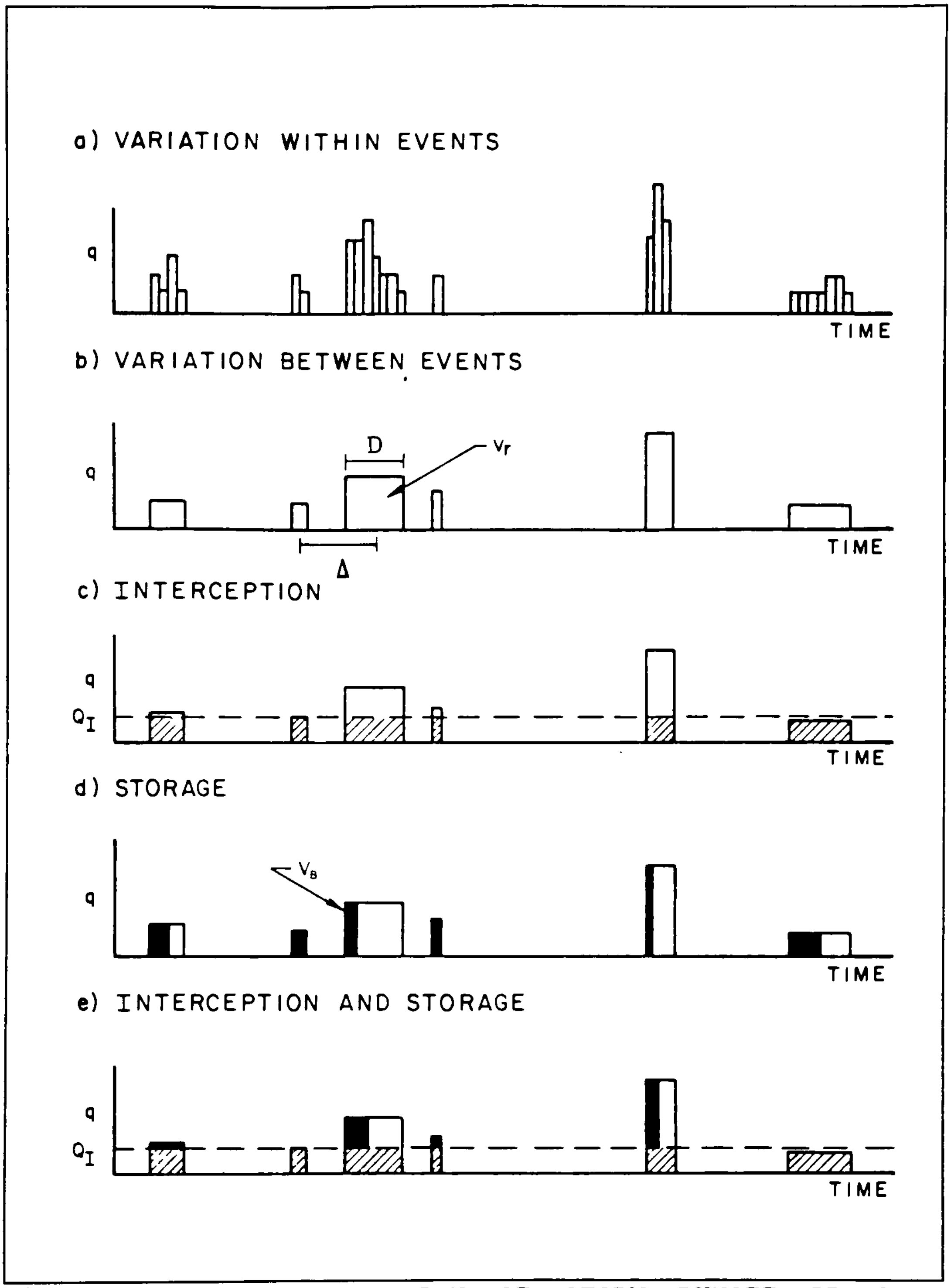


Figure 3.1: PRESENTATION OF STORM RUNOFF PROCESS, INTERCEPTION AND STORAGE [23, pg. 3-47.]

3.2 SEDIMENTATION PROCESS

Theoretical analysis of the sedimentation process is usually based upon several critical assumptions. These are:[10]

1) The basin operates like an idealized rectangular continuous flow basin

2) The direction of flow is horizontal

3) The velocity is uniform in all parts of the settling zone

4) The concentration of suspended particles of each size is the same at all points in the vertical cross-section at the inlet end of the basin

5) Particles are removed when they reach the bottom of the basin

6) "Plug flow" is assumed

7) Stoke's Law is valid for deriving settling velocities.

3.3 SETTLING VELOCITY OF PARTICLES IN URBAN RUNOFF

Any analysis methodology for estimating the performance of a detention basin for water quality through sedimentation requires information on the settling velocity of particles in urban runoff. An important contribution in this area was made by the National Urban Runoff Program (NURP) [4] when data was collected which verified previous estimates on settling velocities. Settling tests were conducted for a number of NURP projects of varying samples of urban runoff. According to the EPA [4], the analysis of 46 separate settling column tests indicates that:

- There is a wide range of particle sizes and, hence, settling velocities in any individual urban runoff sample
- The distribution of settling velocities can be adequately characterized by a log-normal distribution
- There is substantial storm-to-storm variability in median settling velocity at a specific site.
- No significant differences between site-to-site mean distributions have been identified. The within-site variability is on the same order as potential site-to-site differences.
- Assuming the data available for analysis are representative, the foregoing indications, with regard to storm-to-storm and site-to-site differences support the pooling of all available data to define "typical" characteristics of particle settling velocity distributions in urban runoff, and the assumption that such results are generally transferrable to other urban runoff sites.

The typical particulate distribution is broken into five size fractions as shown in Table 3.1.

TABLE 3.1: AVERAGE PARTICLE SETTLING VELOCITIES

Size Fraction	% of Particle Mass in Urban Runoff	Average Settling Velocity (ft/hr)
1	0 - 20%	0.03
2	20 - 40%	0.3
3	40 - 60%	1.5
4	60 - 80%	7.0
5	80 - 100%	65.0

4.0 METHOD

In order to determine if the NYDEC requirements are appropriate for the central and western New York State Region a model must be implemented to estimate the runoff water quality with a detention basin designed to NYDEC guidelines. There are a myriad of methods available to predict urban runoff quality, but this study had several requirements:

1. Portable and simple to use in order to facilitate use as a planning tool for future projects
2. Utilizes theory based on sedimentation only since sedimentation is the primary mechanism for removal in detention basins. Biological uptake, the primary mechanism for dissolved pollutant removal, is beyond the scope of this thesis.
3. Is based upon hourly precipitation data which is readily available for New York state and other geographic regions.

Taking into account the above criteria, an EPA [4] method was chosen.

5.0 METHOD OF ANALYSIS

5.1 GENERAL

The EPA method [4] utilizes performance estimates for detention basins computed using probabilistic analysis procedures conceived and formulated by DiToro and developed by DiToro and Small [3,17]. These procedures provide a direct solution for the long term average removal of suspended solids. The variable nature of storm runoff is treated by specifying the rainfall and runoff it produces in probabilistic terms. This is accomplished by the examination of long-term precipitation records. The methods employed in the rainfall analysis are discussed later.

The measure of performance employed in this method [4] is the long-term average reduction in mass loading, or in other words, the long-term average removal of total suspended solids. This is considered an appropriate measure for two reasons. First it recognizes the highly inconsistent nature of urban storm runoff and concentrates on long-term averages instead of individual events. This is crucial since a detention basin of fixed size will have higher removal efficiencies during some storm events and lower efficiencies in others. Second, there is a direct correlation with methods adopted by NURP (National Urban Runoff Program) for characterizing the impacts of storm runoff on water quality of receiving waters.[4]

The specification of the design capacity of a detention basin is inherently ambiguous due to the variability of individual storm events and the resulting runoff. This is influenced by several factors: regional differences in rainfall patterns, size of the drainage area, the land use distribution of the areas, the impervious cover and the amount of runoff that any particular storm generates.[4] In order to alleviate some of this ambiguity, the method specifies rainfall/runoff rates, volumes, duration, and intensities as a mean and a coefficient of variation. (Coefficient of variation (CV) is defined as the standard deviation divided by the mean over time.)

5.2 COMPUTER IMPLEMENTATION

As part of this work, the method described in the subsequent sections was incorporated into a computer model. The model is a computer program written in Fortran 77 computer code. Although run on a VAX system, no VAX resident programs were used in the model allowing the program to run on any system, including a PC with a Fortran compiler.

Several portions of the methodology could be programmed directly and the implementation of these will not be discussed in detail. However, several of the equations involved required numerical solutions and the implementation of these will be described along with the theory.

5.3 RAINFALL

5.3.1 DATA

The long-term record of hourly precipitation data for the Rochester, New York area was obtained through the National Climatic Data Center in Asheville, North Carolina. The data contains hourly precipitation records taken at the Rochester, NY U.S. Weather Service (USWS) station, ID# 307167, from May 1948 to March 1993. A sample listing of the data is in the appendix.

5.3.2 ANALYSIS

As mentioned previously, the rainfall statistics required for use with the EPA method are the mean and coefficient of variation for the following storm event parameters:

Volume (V)	inches
Intensity (I)	in/hr
Duration (D)	hr
Interval (Δ)	hr

In order to calculate these, the hourly rainfall records must be separated into discrete storm events. This requires that the end of a storm be identified. This is specified by a minimum number of consecutive dry hours that distinguishes the end of the storm event, called the minimum inter-event time (MIT) and several methods are available for determining this.[23]

The method used in this study is based upon the characterization of the rainfall process as a random, Poisson process.[23] From this, it is assumed that the time between events (Δ) is an exponentially distributed random variable, which is equivalent to a gamma distributed variable with a coefficient of variation (CV_Δ) equal to one. Therefore, the criteria for dividing the precipitation data into discreet storm events (selecting the appropriate number of dry hours or MIT) is such that the CV_Δ will equal one.

A computer program has been previously written and is available through the National Technical Information Service (NTIS). This program, Synoptic Rainfall Data Analysis Program or SYNOP, provides the user with a tool for summarizing and statistically analyzing long-term rainfall records such as the hourly data utilized here. SYNOP estimates the MIT iteratively, using the method discussed above, and then calculates a summary of storm event data along with the statistics of the storm parameters. Output includes statistics on storm duration, storm intensity, storm volume, and time between storm midpoints, by month and year for the entire period of record. A printout of a SYNOP run is located in the Appendix.

5.4 SEDIMENT REMOVAL MECHANISMS

A fundamental aspect of any detention basin relying on sedimentation as its principal pollutant removal mechanism is that there are certain periods, while runoff inflow occurs, in which stormwater is moving through the basin and sedimentation takes place under dynamic conditions. During the dry periods between storm events, sedimentation takes place under quiescent conditions. Removal under both dynamic and quiescent conditions are used here, as discussed below.

5.4.1 TSS REMOVAL UNDER DYNAMIC CONDITIONS

Sedimentation devices, such as detention basins, can not be characterized by a static column of water. Flow conditions may be laminar, turbulent, or a mixture of both, and sedimentation is greatly affected by the degree of turbulence in the flow. Performance of such sedimentation devices has been extensively analyzed because of their important role in wastewater treatment systems. A method of analysis particularly useful to this study was developed by Fair and Geyer [22] and characterizes removal due to sedimentation in a dynamic (flow through) basin. Removal is expressed in the following equation:

$$R_M = 1 - \left[1 + \frac{1}{n}\,\frac{V_s}{\frac{Q}{A}}\right]^{-n} \qquad (1)$$

Where:

R_M	=	fraction of initial solids removed at mean overflow rate (R_M * 100 = % Removal)
V_s	=	settling velocity of particles (ft/hr)
Q	=	peak flow-through rate (ft^3/hr)
A	=	surface area of the detention basin (ft^2)
Q/A	=	rate of applied flow divided by surface area of basin (an "overflow velocity", often designated the overflow rate)
n	=	turbulence or short circuiting constant that is used to indicate settling performance

One merit of this model is that it provides a quantitative means of factoring into the analysis an expression for impaired performance due to short-circuiting. Short circuiting may cause incomplete mixing in the basin before outflow and/or turbulent flow conditions. Turbulent flow may result in higher velocities and reduced sedimentation efficiency. This short-circuiting factor is especially valuable as many stormwater detention basins will not have model geometry required to produce conditions ideal for maximum removal of pollutants through sedimentation. The empirical relationship between performance and the value of "n" follows: [22]

n = 1, poor performance

n = 3, good performance

n > 5, very good performance

n = ∞, ideal performance

For a value of n = ∞ (ideal performance), equation (1) reduces to the following, wherein removal efficiency is directly correlated to detention time.

$$R_M = 1 - \exp\left[- \frac{v_s}{\frac{Q}{A}}\right] \qquad (2)$$

or

$$R_M = 1 - \exp[-kt] \qquad (3)$$

where:

k	=	v_s/h (sedimentation rate coefficient)
h	=	average depth of basin (ft)
t	=	V/Q (residence time) (hr)
V	=	volume of basin (ft^3)

Equations (2) and (3) are equivalent.

Equation (1) is solved for a range of overflow rates (Q/A), particle settling velocities (v_s) and plotted in figure 5.1. for various values of the short circuiting parameter (n).

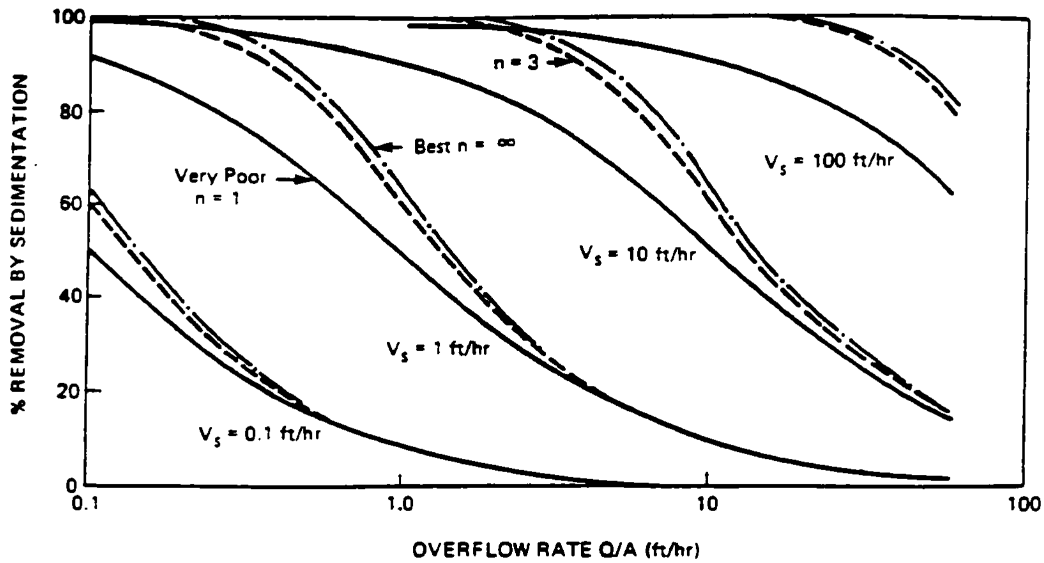


FIGURE 5.1: EFFECT OF SETTLING VELOCITY AND OVERFLOW RATE ON REMOVAL EFFICIENCY [4, PG. 28]

As discussed previously, storm sequences result in variable overflow rates. Removal efficiencies will consequently vary greatly. Equation (1) and the resulting analysis make the following assumptions: [4]

- The short-term variability of flows (within storm events) is small compared with the variability of average flows between storms. To the extent that this is not the case, equation (1) will overestimate long-term performance.

- Storm flows and pollutant concentrations are independent. If flow rate and concentration are negatively correlated (high flows produce lower concentrations), performance will be better than indicated. For positive correlations, performance will be poorer than indicated.

- Removal efficiency is an exponential function of flow.

The next step in the procedure is to address the performance of the detention basin under variable input flows, when the removal efficiency for a pollutant varies with the rate of applied flow. This is especially suitable for detention basins as they are less efficient in removing pollutants at high flow-through rates and more efficient at lower flow-through rates. Equation 4 calculates the long-term average fraction of total solids removed (R_L) for variable runoff flows, which are assumed to be gamma distributed, entering a detention basin.

$$R_L = Z\left[\frac{r}{r - \ln\left[\frac{R_M}{Z}\right]}\right]^{r+1} \tag{4}$$

where:

R_L = long term average fraction of TSS removed for variable runoff flows entering a basin (%)

R_M = fraction removed at mean runoff rate

r = $1/CV_q2$

CV_q = coefficient of variation of runoff flow rates

Z = maximum fraction removed at very low rates (Z is assumed to be 100% for this model)

A graphic solution to equation 4 is shown in Figure 5.2. The plot illustrates the effect variable stormwater flows have on long-term performance.

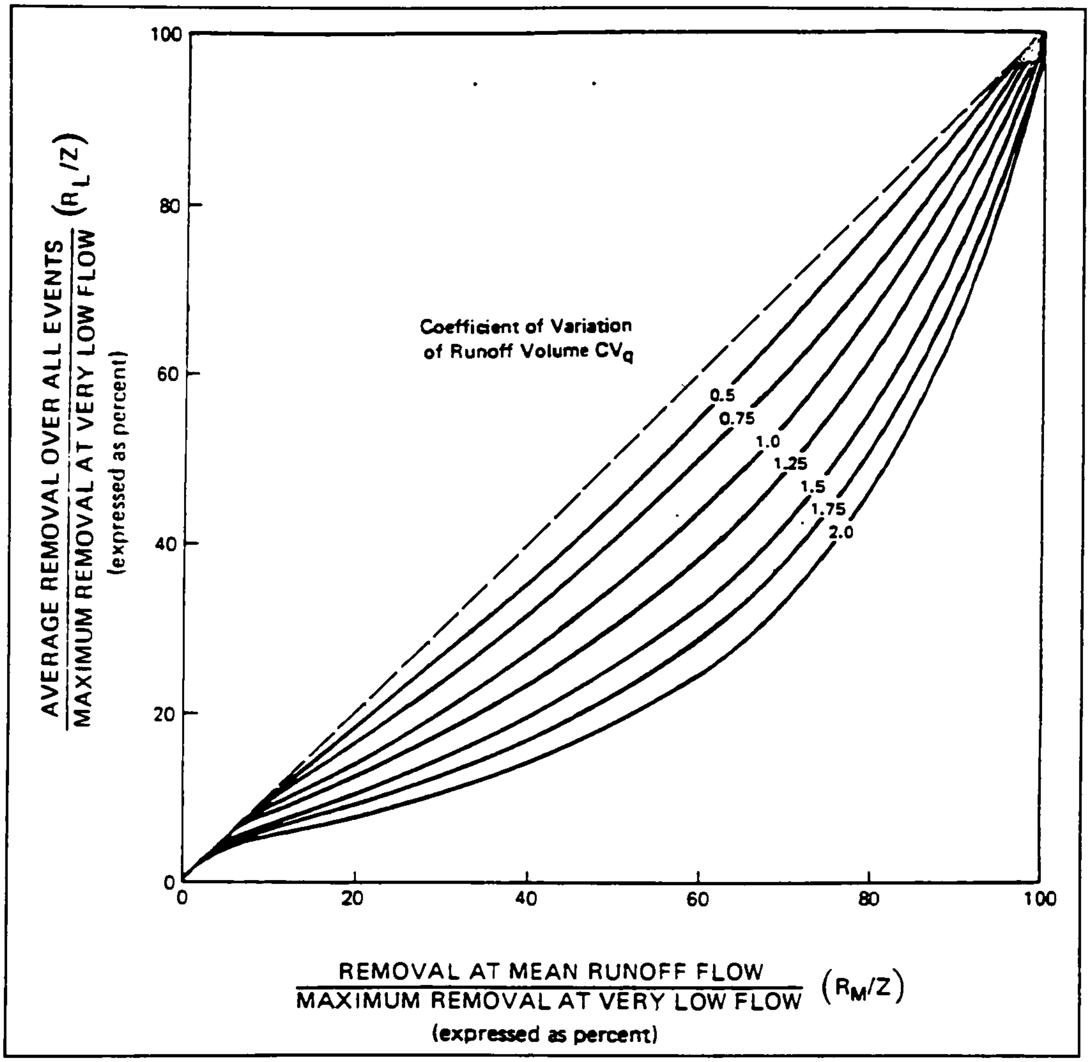


FIGURE 5.2: LONG TERM PERFORMANCE OF A DEVICE WHERE REMOVAL MECHANISM IS SENSITIVE TO FLOW RATE [4, pg. 8]

The long term average fraction of sediment removed from the urban stormwater (R_L) can next be calculated for each particle size fraction. The overall average removal of sediment under dynamic conditions is calculated by taking the mean of the long term average fraction of sediment removed (R_L) from each particle size fraction contained in the stormwater.

5.4.2 TSS REMOVAL UNDER QUIESCENT CONDITIONS

Surface storm runoff occurs only during a fraction of the time in any given year. For the Rochester, NY area; the average storm duration is 7.09 hours and the average interval between storms is 60 hours or 2.5 days, as discussed later. As a result of this inter-storm delay, a significant amount of runoff can be retained in a detention pond allowing sedimentation to continue under relatively quiescent conditions before being disturbed by another storm event. The basin volume, relative to storm runoff volume, is a controlling factor in determining the TSS removal effectiveness under such quiescent conditions.[4]

One complicating factor is that the total storage volume of the detention basin may not be available at the start of a new storm event, as the basin may still have remaining runoff from previous storms. The basin storage that is available on average is termed the effective storage volume, V_E, and will be the most important determinant of the long-term performance of the basin.[3]

This is best illustrated by considering the situation outlined in figure 5.3. It is assumed that the basin begins with the full long-term effective storage capacity (V_E) available. The portion of the basin represented by "V_B-V_E" can be interpreted as the volume of water remaining in the basin due to it's extended detention time design. Upon the storm event labeled "STORM 1", a volume of rain (ν) further fills the basin. Preceding the next storm labeled "STORM 2", the basin empties at a constant discharge rate Ω. The basin then has an available storage capacity of V_e at the beginning of STORM 2.

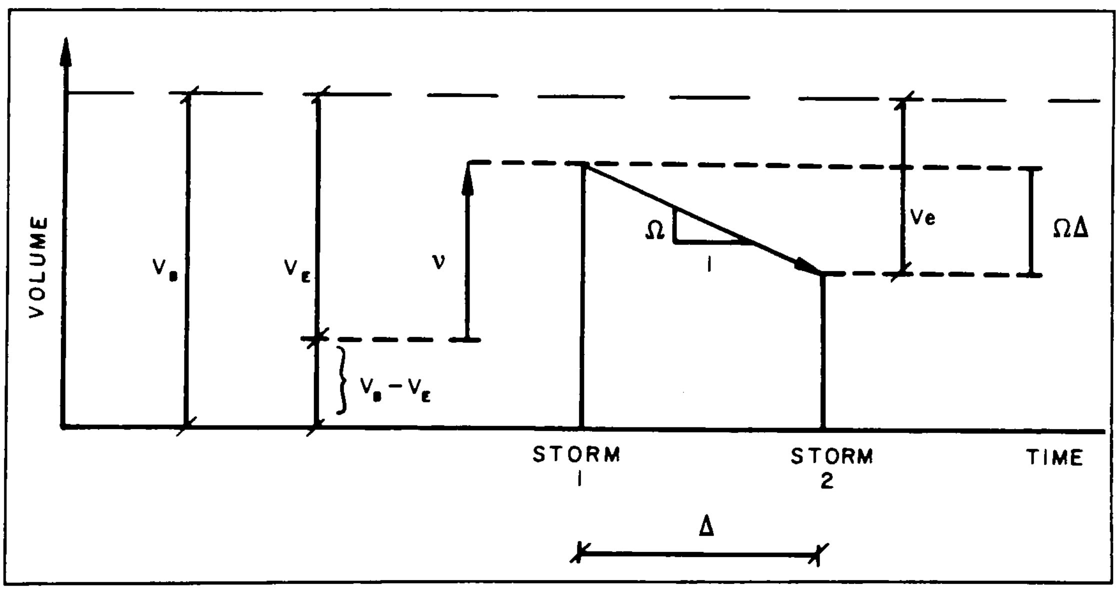


FIGURE 5.3: EFFECT OF PREVIOUS STORMS ON BASIN VOLUME [3, pg. 47]

The problem is to find the expectation of V_e over all possible values of ν and Δ. This expectation of V_e is the long-term effective volume of the basin, V_E, and may be calculated as shown in equation 5.[3,23]

$$V_E = \int_{\Delta} \int_{\nu} V_e \, p_{\Delta}(\Delta) p_{\nu}(\nu) d\nu d\Delta \tag{5}$$

where:

V_E	=	Long-term effective volume of the basin (ft^3)
$p_{\Delta}(\Delta)$	=	probability density function of average interval between storms (Δ)
$p_{\nu}(\nu)$	=	probability density function of volume of rain (ν)

This integral may be solved for the special case when the runoff flow durations and the time between storms are exponentially distributed and independent. In this case, it has also been shown that the probability density function for storm volume is:[3]

$$p_{\nu}(\nu) = \frac{2}{V_R} K_0 \left(2\sqrt{\frac{\nu}{V_R}} \right) \tag{6}$$

where:

K_0	=	modified Bessel function of the second kind

Upon utilization of equation 6, the resulting V_E, as developed by DiToro and Small [3], is given by equation 7.

$$V_E = 2\Delta\left(1-\exp\frac{-V_B}{\Delta\Omega}\right)\sqrt{\frac{V_E}{V_R}}\,K_1\left(2\sqrt{\frac{V_E}{V_R}}\right) + \frac{2}{V_R}\cdot \int_{\nu=0}^{V_E}\left[-(\Delta\Omega)\exp\left(-\frac{\nu+V_B-V_E}{\Delta\Omega}\right)-\nu+V_E+\Delta\Omega\right]K_0\left(2\sqrt{\frac{V}{V_R}}\right)d\nu \qquad (7)$$

where:

V_E	=	effective volume of basin (ft^3)
Δ	=	interval between storms (hr)
Ω	=	emptying or discharge rate (ft^3/hr)
V_B	=	volume of basin (ft^3)
V_R	=	volume of runoff (ft^3)
$K_{0,1}$	=	modified Bessel function of the second kind
ν	=	volume of rain which fills the basin (ft^3)

The above is a non-linear integral equation for V_E. The solution requires a numerical evaluation of the definite integral at each iteration of any root finding method used. The root finding method used here was the Secant method and the numerical integration was implemented using Simpson's rule. Successive substitution, starting with $V_E=V_B$, is found to converge rapidly. The results, normalized by the mean runoff volume V_R are displayed in figure 5.4.

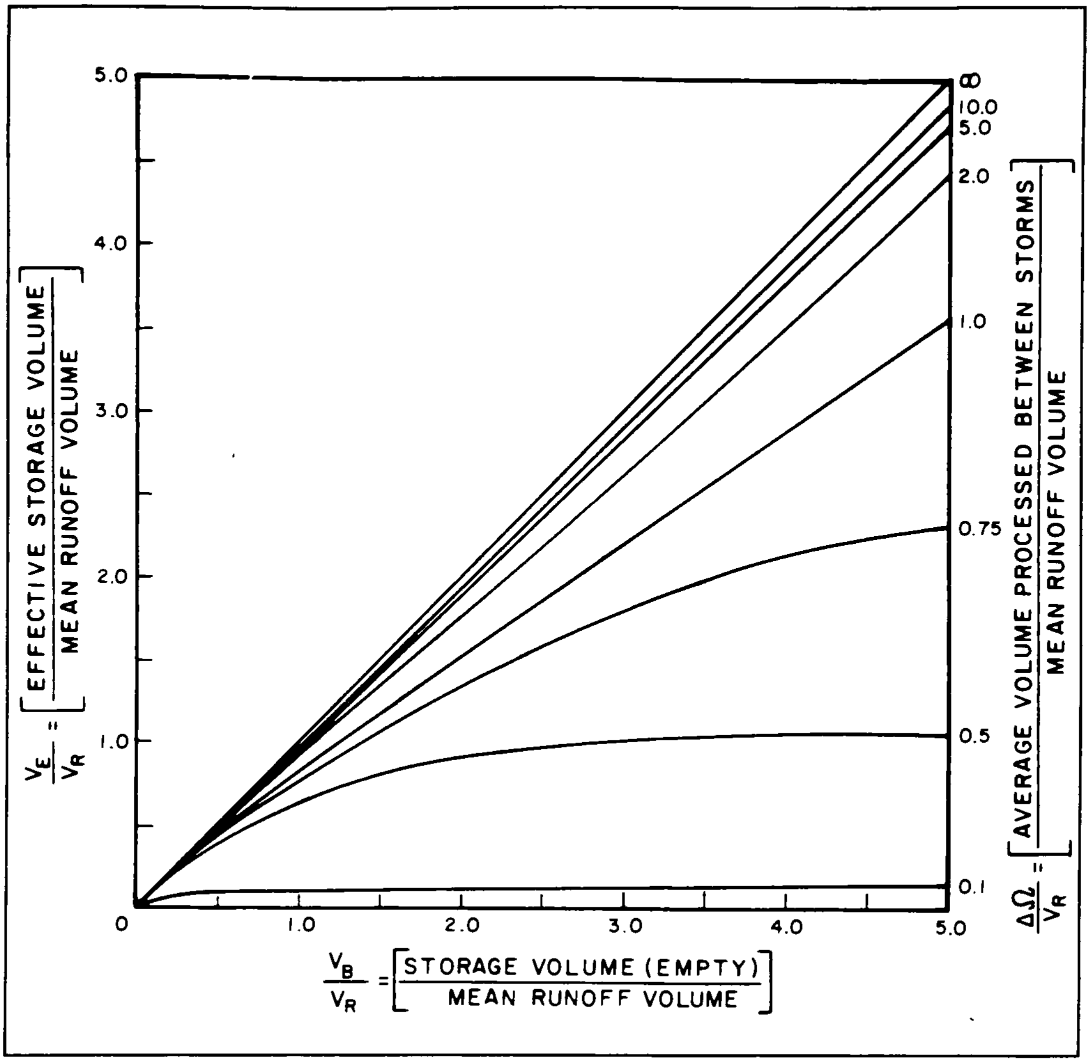


FIGURE 5.4: EFFECT OF PREVIOUS STORMS ON LONG-TERM EFFECTIVE STORAGE CAPACITY [23, pg. 3-77]

Once the effective storage capacity has been determined, the analysis of basin performance, expressed as a removal rate, may proceed. When analyzing a detention basin it is obvious that its effectiveness in removing suspended solids is a function of its storage volume. The basin captures runoff flow until it has reached maximum capacity (V_B) and, thereafter, all additional stormwater will pass by the basin untreated. The captured stormwater will then be slowly removed from the basin at a rate determined by the emptying rate (Ω). The long term fraction of the runoff load, f_v, not captured by the detention basin is calculated as the expectation of the bypassed runoff load divided by the total runoff load:[3]

$$f_v = \frac{\overline{M}}{M_R} \tag{8}$$

where:

$\overline{M}$ = the mean bypassed load per storm (mass)

M_R = total runoff load (mass)

Equation 8 can be transformed into the form shown in equation 9 [3,4], which then allows a solution using parameters previously calculated. Equation 9 assumes that the storm volumes are gamma distributed.

$$f_v = \frac{r_1^{r_1} \cdot r_2^{r_2}}{\Gamma(r_1) \cdot \Gamma(r_2)} \int_{q=0}^{\infty} q_1^{r_1} \exp\left[r_2 \frac{V}{q}\right] \exp\left[-r_1 q\right] \cdot \int_{\Delta=0}^{\infty} \Delta \left[\Delta + \frac{V}{q}\right]^{r_2 - 1} \exp\left[-r_2 \Delta\right] d\Delta dq \tag{9}$$

where:

r_1 = $1/CV_q^2$ and r_2 = $1/CV_d^2$

CV_q = coefficient of variation of runoff flow rates

CV_d = coefficient of variation of runoff durations

q = storm runoff flow rate (ft^3/hr)

Δ = average interval between storm midpoints (hr)

V = basin effective volume, divided by mean storm runoff volume (V_E/V_R)

f_v = fraction of all volumes NOT captured by basin

$1-f_v$ = sediment removed ((1-fv)*100 = % of sediment removed)

The double integral in equation 9 cannot be evaluated analytically. The numerical technique used here is Laguerre quadrature with weighted polynomials. The basic equation transformation using quadratures follows:[4]

$$f_v = \frac{r_1^{r_1} \cdot r_2^{r_2}}{\Gamma(r_1) \cdot \Gamma(r_2)} \sum_{k=1}^{n} w_k \cdot g[x_k] \left[\sum_{j=1}^{n} w_j \cdot f[x_j, x_k] \right] \qquad \textbf{(10)}$$

where:

$$g(x_k) = \left[\frac{x_k}{r_1}\right]^{r_1} \cdot \left[\frac{1}{r_1}\right] \cdot \exp\left[-r_1 \cdot r_2 \cdot \frac{V}{x_k}\right]$$

$$f(x_j, x_k) = \left[\frac{x_j}{r_2}\right] \cdot \left[\frac{1}{r_2}\right] \cdot \left[\frac{x_j}{r_2} + \frac{r_1 V}{x_k}\right]^{r_2 - 1}$$

n = number of orders used in integration (n=10)

x_j, x_k, w_j, w_k = abcissas and weights for Laguerre Integration (listing is found in the program code in the appendix)

In order to understand the relationship between volume and percent removal of sediment under quiescent conditions, the above equation was solved for a range of volumes (V_E/V_R) and several commonly used coefficient of variations of runoff flow rates (CV_q), as shown in figure 5.5.

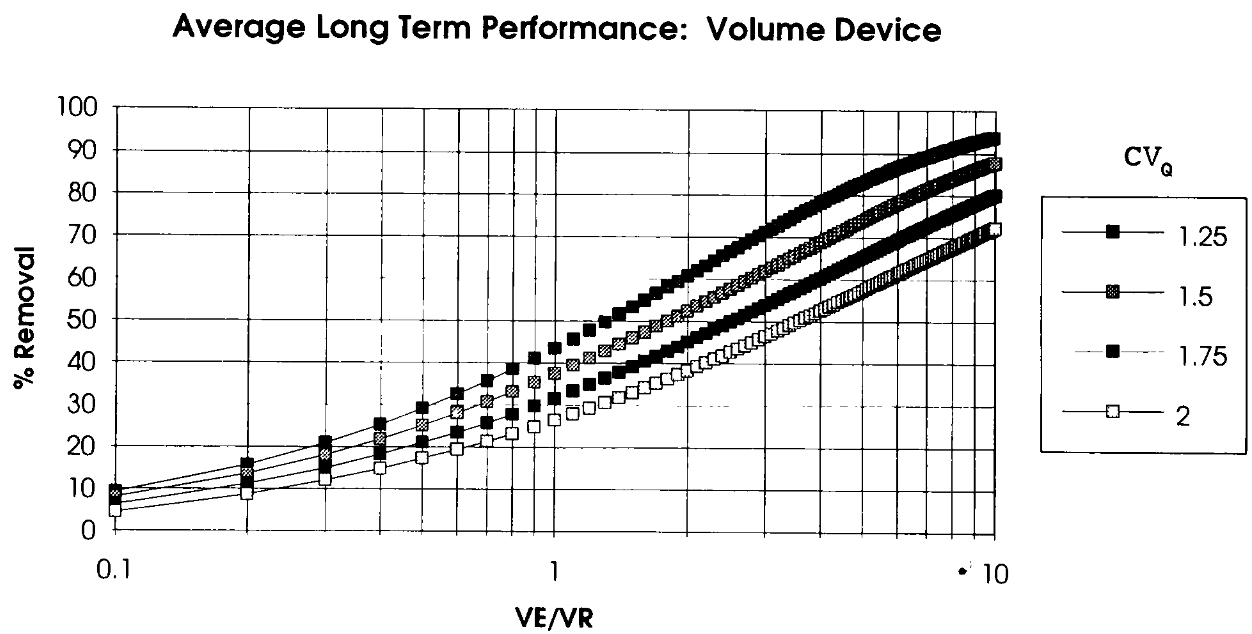


FIGURE 5.5: AVERAGE LONG TERM PERFORMANCE, QUIESCENT CONDITIONS: VOLUME DEVICE

The overall average removal of sediment from the stormwater under quiescent conditions can now be determined by calculating the percent removal (equation 9) for each particle size fraction.

The combined total average long-term TSS removal from the stormwaters is calculated from the fraction of sediment not removed under both quiescent and dynamic conditions as shown in equation 11.

$$f_Q = (100 - OAR_Q)/100$$
$$f_D = (100 - OAR_D)/100 \qquad \textbf{(11)}$$

where:

- f_Q = fraction NOT removed under quiescent conditions
- f_D = fraction NOT removed under dynamic conditions
- OAR_Q = Overall average sediment removal under quiescent conditions
- OAR_D = Overall average sediment removal under dynamic conditions

The final % TSS removed is calculate by combining the fraction not removed under quiescent conditions and the fraction not removed under dynamic conditions as illustrated in equation 12.

$$\%Removed(overall) = [1 - (f_Q \cdot f_D)] \cdot 100 \qquad \textbf{(12)}$$

6.0 EPA MODEL VALIDATION

The EPA used performance data from nine wet pond detention basins in order to test the reliability of the above outlined method.[4] Figure 6.1, adapted from [4], compares the observed and predicted performance for these nine wet ponds. Upon inspection of figure 6.1, it is noticeable that there are two outliers, sites 4 and 6, when examining predicted versus observed performance of TSS removal. Both sites were found to have existing problems, bank erosion and a large population of ducks, which skewed the data. On the basis of the comparison of the other sites the analysis methodology used appears to provide sufficiently reliable estimates of performance for use in planning activities.

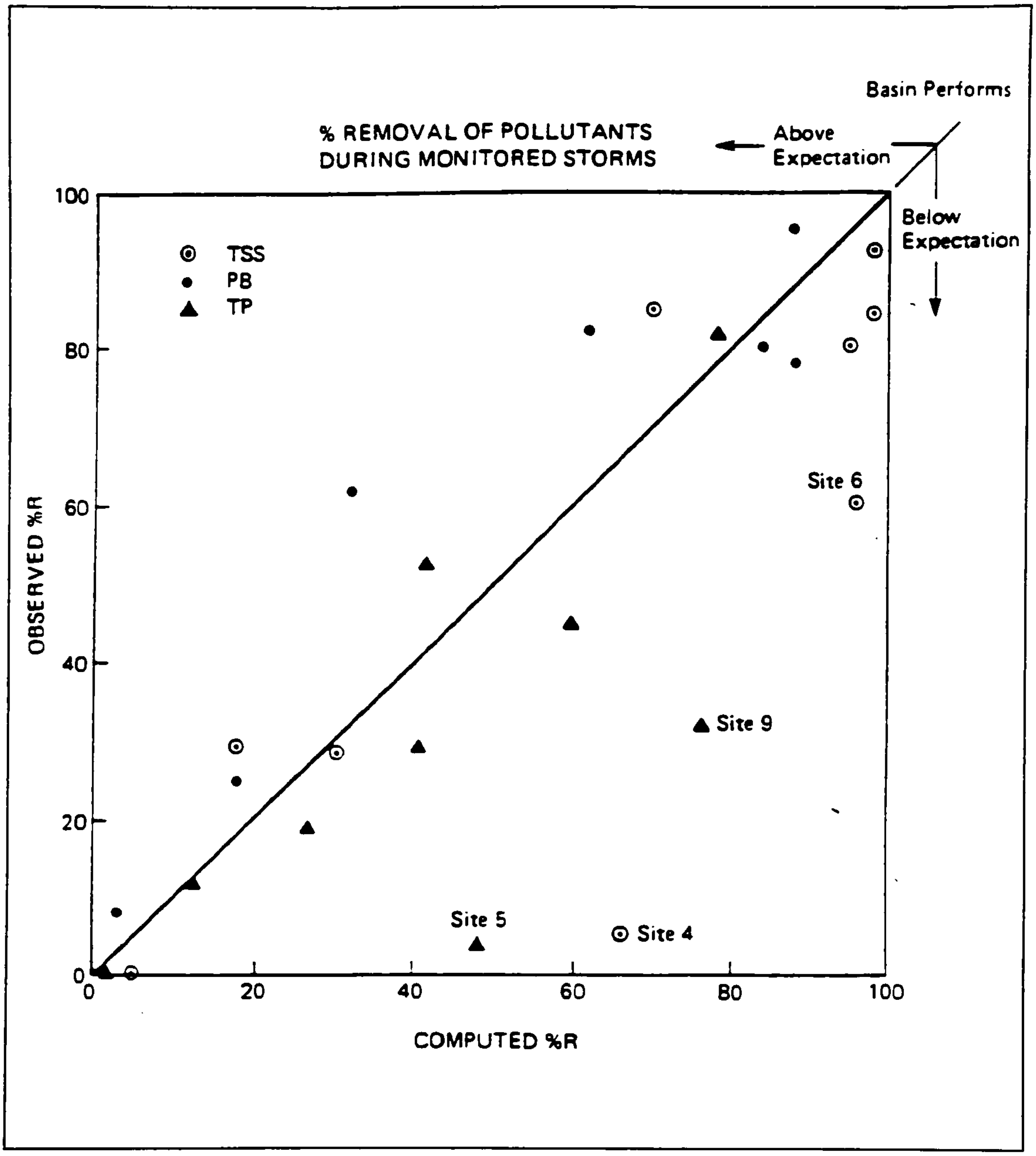


FIGURE 6.1: COMPARISON OF OBSERVED VS. COMPUTED REMOVAL EFFICIENCIES [4, pg. 38]

7.0 APPLICATION

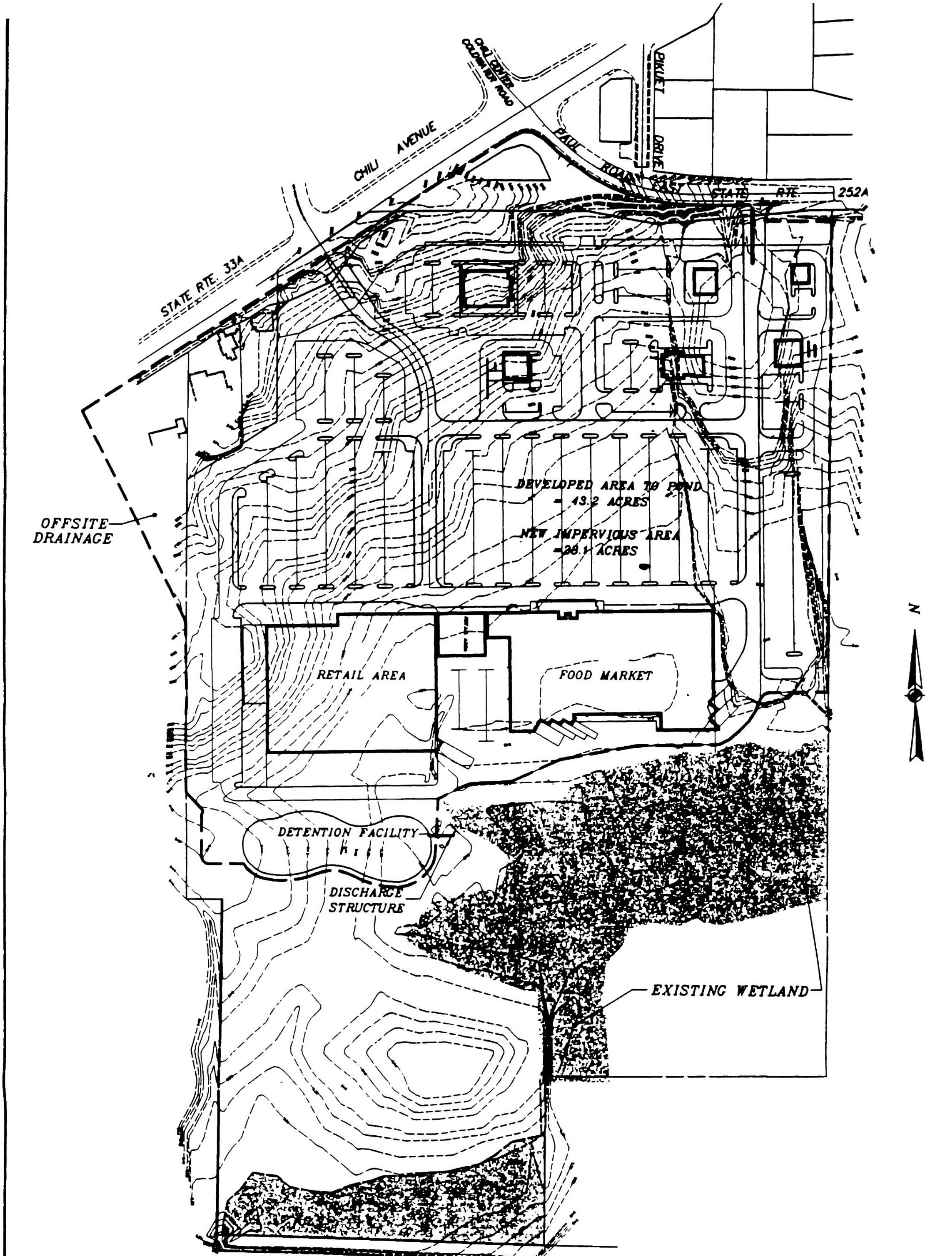
7.1 CASE STUDY

7.1.1 SITE BACKGROUND

In order to determine if the NYDEC guidelines for the design of extended detention basins are adequate in terms of water quality improvement in western and central New York, a site was chosen with an existing detention pond for which site data was available. The site is a newly developed, 302,000 square foot, retail shopping center by Wegman's Food Markets, Inc. It is situated on a 65.9 acre parcel of land in the Town of Chili, Monroe County, New York. The project includes a 120,000 square foot food market, an additional 154,000 square feet of attached retail space, and six out parcels containing a total 27,800 square feet of restaurant, retail, and service use. Paved parking is included for a total of 1,720 vehicles.[25] This area was fallow farm land prior to development. Figure 7.1 shows a map and site plan for the project.

7.1.2 BASIN DESIGN

Hydrologic modeling was performed for this site to assess drainage characteristics. Pre-development site drainage was via overland and shallow channel flow. The watershed of concern for stormwater analysis is a 43.2 acre portion of the property. Table 7.1 summarizes the total volume and peak



PROJECT ENGINEER: M.R.C.

DRAWN BY: P Mc.

DATE: 12/9/92

SCALE: 1"= 200'

CHARLES J. COSTICH
P.E.,L.S.,P.C.

217 LAKE AVENUE
ROCHESTER, NEW YORK 14608
716-458-3020

LOCATION OF PROJECT: CHILI–PAUL WEGMANS

TITLE OF DRAWING: DRAINAGE AREA MAP

LOCATION OF PROJECT: TOWN OF CHILI

CLIENT: WEGMANS FOOD MARKETS, INC.
1500 BROOKS AVENUE, ROCHESTER, N.Y. 14624

DWG NO: 678D

rates of runoff for this watershed under pre-development conditions. These values were calculated using the USDA Soil Conservation Method (TR-55) by the project engineer, Charles J. Costich, P.E.,L.S.[25]

TABLE 7.1: PRE-DEVELOPMENT RUNOFF CONDITIONS - PROJECT CASE STUDY

Storm Return Period (years)	Total Volume of Runoff (acre-ft)	Peak Rate of Discharge (cfs)
2	1.33	10.52
10	3.35	33.25
100	6.59	70.47

Post-development, all stormwater runoff from the site is conveyed via subsurface pipe from storm inlets to a new detention pond southwest of the food market location. Table 7.2 summarizes the total volume and peak rates of runoff under post-development conditions.

TABLE 7.2: POST-DEVELOPMENT RUNOFF CONDITIONS - PROJECT CASE STUDY

Storm Return Period (years)	Total Volume of Runoff (acre-ft)	Peak Rate of Discharge from Detention Pond (cfs)
2	5.58	6.08
10	9.22	32.83
100	14.04	95.06

The detention pond is approximately 1.5 acres in size and provides 6.0 acre-feet of available storage. The design goal for the pond was to detain high frequency runoff events over a time sufficient to allow for removal of stormwater pollutants.

It is of interest, at this point, to compare the design of the project basin with the NYDEC guidelines. As outlined previously, there are two guidelines most meaningful for effective removal of suspended pollutants in an extended detention basin. These are that the volume of runoff detained should be equivalent to the runoff volume produced by either the first ½ inch of runoff or runoff from a 1-year, 24 hour storm event, whichever is larger. Also, the runoff should remain in an extended detention basin for a minimum of 24 hours to allow for sedimentation to occur.[12] Again, as stated previously, other studies [13 & 16] state that the detention time should be an <u>average</u> of 24 hours.

The detention pond outlet structure was designed to provide an outflow rate sufficient to allow adequate detention time for pollutant removal through sedimentation. Figure 7.2 shows a plot of the outflow from the detention pond for the 1-yr, 24 hour storm. The total time required to empty the basin is found to be in excess of forty hours, which, according to the Northern Virginia Planning District Commission [13] would result in an average detention time of 24 hours. The project basin, thus, provides a longer detention time than the minimum 24 hours outlined by the NYDEC.

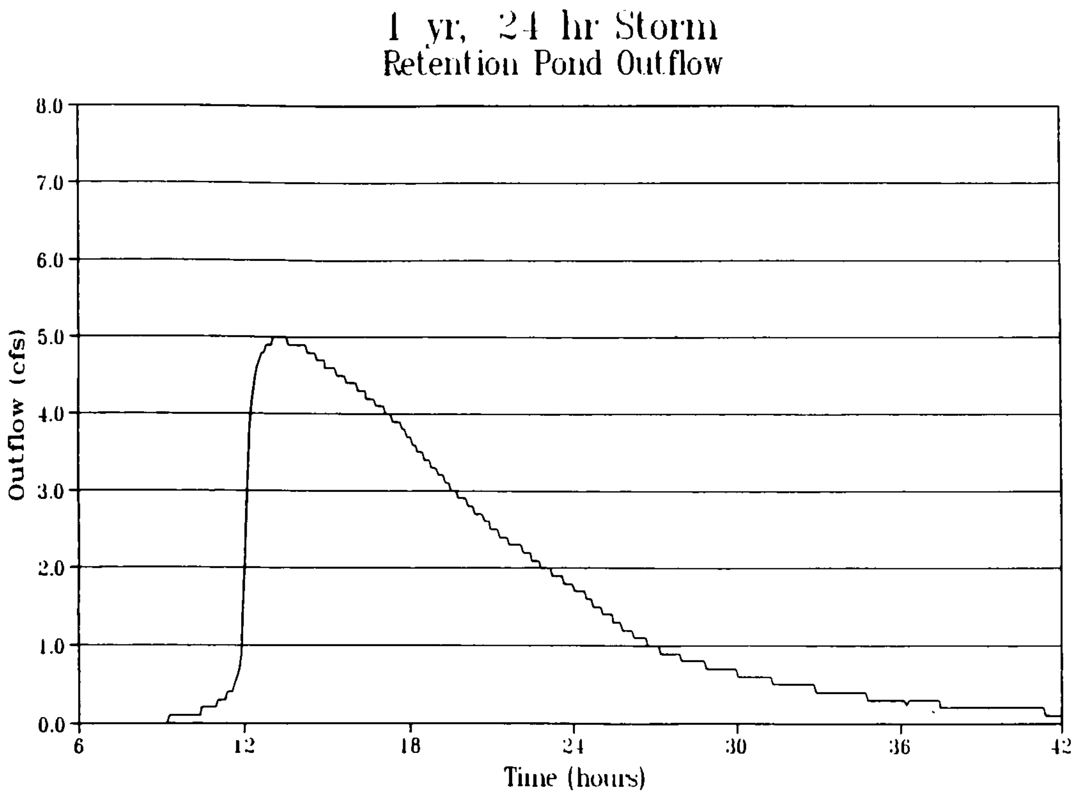


FIGURE 7.2: 1-YR, 24 HR. STORM, DETENTION POND OUTFLOW - PROJECT CASE STUDY

The basin storage volume was then addressed in the design. The volume of runoff generated from the 1-yr, 24 hour storm is

4.61 acre-ft. This number was found by multiplying the 24-hour runoff of 1.28 inches or .107 feet, generated using the Soil Conservation Service Method, by the total watershed area of 43.2 acres. In comparison, the volume of runoff generated from one-half inch of runoff from all impervious surfaces, approximately 28.1 acres, is 1.2 acre-ft. Taking the larger of the two runoff values, per the NYDEC guidelines, the required storage volume for the basin would be 4.61 acre-ft. As stated earlier, the detention pond provides a total storage volume of 6.0 acre-feet. Thus, the detention pond is again slightly over designed with regard this NYDEC guideline.

7.1.3 RAINFALL ANALYSIS

As mentioned previously, the computer program SYNOP was used to access the local meteorological data for the Rochester, NY area. SYNOP uses hourly precipitation records, taken at the Rochester, NY U.S. Weather Service Station from May 1948 to March 1993, and outputs various precipitation statistics. The precipitation statistics critical to the basin analysis to follow are found in table 7.3

TABLE 7.3: PRECIPITATION STATISTICS FOR THE ROCHESTER, NY AREA USED IN BASIN ANALYSIS (CALCULATED BY SYNOP)

STORM PARAMETER	MEAN VALUE	COEFFICIENT OF VARIATION
Volume	.22 in	1.55
Duration	7.1 hr	1.15
Intensity	.034 in/hr	1.51
Interval or Delta	60 hr	*

*Not required in basin analysis

7.1.4 PROJECT BASIN ANALYSIS

For this analysis, the 1-yr, 24 hour storm, was used. Although the larger 10 year and 100 year storms generate a much greater volume runoff, it has been shown, as discussed previously in the literature review, that the runoff from minor to moderate storm events are of greater interest from a water quality management standpoint than the less frequent flood-producing rainstorms.[13] The 1-yr storm inflow hydrographs for reservoir routings were generated using the Soil Conservation Service Method. Although the method used to calculate total sediment removal, described in the previous sections, calculates the volume of runoff from the watershed (V_R) by using equation 13, it was determined that the results would be more accurate by using the actual volume runoff of

4.61 acre-ft or 200,812 ft^3 calculated via the inflow hydrograph.[25]

$$V_R = V \cdot C_v \cdot A \tag{13}$$

where:

V_R	=	volume runoff (ft^3)
V	=	rainfall volume (ft)
C_v	=	runoff coefficient
A	=	watershed area (ft^2)

The average discharge rate (omega) was also obtained from the hydrograph. This was accomplished by calculating an average outflow rate to the point in time when 90% of the total outflow of the basin has occurred. (Only 90% of the outflow was used in order to eliminate the long, low flow tail which tends to skew the data.)

The parameters used in the computer run along with the resulting output, is shown in table 7.4, case number 1. (See appendix for actual computer run print out.) Analysis for the project detention basin was performed three times using the full range of short circuit parameters (n) discussed previously. As the table shows the overall average TSS removal rates, for the project basin, range from 85.4% to 90.4%.

7.1.5 NYDEC BASED DETENTION BASIN ANALYSIS

Since the topic of this thesis is the analysis of the NYDEC guidelines for extended detention basins, it is of value at this point to analyze alternate detention basin designs adhering strictly to these guidelines. The first basin design follows the guideline of providing enough storage to hold the runoff from a 1-yr., 24 hour storm. For the project watershed and Rochester, NY precipitation data, this value, as mentioned previously, is 4.61 acre-ft. A theoretical detention time can be applied to obtain an average discharge rate (Ω) for the basin. This can be calculated through the use of equation 14.[13]

$$\Omega = \frac{V_B}{t} \tag{14}$$

where:

Ω	=	Average discharge or outflow rate (ft^3/hr)
V_B	=	Volume of basin or storage volume (ft^3)
t	=	Theoretical detention time (hr)

This method is merely an estimate and, since the discharge rate and storage volume of a basin are interrelated, more accurate results could be obtained by using a standard routing method. However, an estimate should be adequate for this analysis.

The parameters used in the analysis and the results of the computer run are found in Table 7.4. Cases two through four all use the runoff from the 1-yr., 24 hour storm as the storage volume. Case two uses the actual average discharge rate calculated for the project basin. The overall average TSS removal is less than the original project design for case number two (81.6% to 87.8%) due to the smaller storage volume available. Cases numbered three and four utilize equation 14 above to obtain a 24 hour and 40 hour total detention time, respectively. (It is important to note that this detention time is a total drawdown time not an average.) The resulting overall average TSS removal for these cases is almost identical to case number two.

The next basin design, cases five and six, implement the NYDEC guideline of providing storage for ½" runoff from all impervious surfaces. As discussed previously, a detention basin with a storage volume of 1.2 acre-ft is required for a watershed with 28.1 acres of impervious surfaces. Again, equation 14 was utilized to apply a theoretical total detention time of 24 hours for case number 5 and 40 hours for case number 6. Table 7.4 lists the parameters and resulting output used in the analysis. The overall average TSS removal for the 1.2 acre-ft storage basin with a theoretical detention time of 24 hours ranged from 62.8% to 71.5%. Again, the results for a basin with a theoretical total detention time of 40 hours is almost identical.

TABLE 7.4: CASE STUDY RUNS WITH RESULTING TSS REMOVAL RATES

CASE #	BASIN		STORM	VR	DISCHARGE RATE (Ω)		SHORT CIRCUIT PARAMETER (n)	OVERALL AVG. DYNAMIC REMOVAL	OVERALL AVG. QUIESCENT REMOVAL	OVERALL AVG. TSS REMOVAL
	TYPE	STORAGE (acre-ft)		(ft^3)	(ft^3/hr)	(cfs)		(%)	(%)	(%)
1	PROJECT	6.0	1-YR	200,812	8173.9	2.27	1	73.6	44.4	85.4
	PROJECT	6.0	1-YR	200,812	8173.9	2.27	3	81.4	44.4	89.7
	PROJECT	6.0	1-YR	200,812	8173.9	2.27	5	82.7	44.4	90.4
2	PROJECT,1 YR 24 HR STORM	4.61	1-YR	200,812	8173.9	2.27	1	37.6	37.6	81.6
	PROJECT,1 YR 24 HR STORM	4.61	1-YR	200,812	8173.9	2.27	3	78.8	37.6	86.8
	PROJECT,1 YR 24 HR STORM	4.61	1-YR	200,812	8173.9	2.27	5	80.3	37.6	87.7
3	NYDEC-24 hr 1 YR, 24 HR STORM	4.61	1-YR	200,812	8367.2	2.32	1	70.6	37.6	81.7
	NYDEC-24 hr 1 YR, 24 HR STORM	4.61	1-YR	200,812	8367.2	2.32	3	78.8	37.6	86.8

CASE #	BASIN		STORM	VR	DISCHARGE RATE (Ω)		SHORT CIRC-UIT PARA-METER (n)	OVERALL AVG. DYNAMIC REMOVAL	OVERALL AVG. QUIE-SCENT REMOVAL	OVERALL AVG. TSS REMOVAL
	TYPE	STORAGE (acre-ft)		(ft^3)	(ft^3/hr)	(cfs)		(%)	(%)	(%)
	NYDEC-24 hr 1 YR, 24 HR STORM	4.61	1-YR	200,812	8367.2	2.32	5	80.3	37.6	87.7
4	NYDEC-40 hr 1 YR, 24 HR STORM	4.61	1-YR	200,812	5020.3	1.39	1	70.6	36.4	81.3
	NYDEC-40 hr 1 YR, 24 HR STORM	4.61	1-YR	200,812	5020.3	1.39	3	78.8	36.4	86.5
	NYDEC-40 hr 1 YR, 24 HR STORM	4.61	1-YR	200,812	5020.3	1.39	5	80.3	36.4	87.4
5	NYDEC-24 hr ½" RUNOFF	1.2	1-YR	200,812	2178	.605	1	56.5	14.3	62.8
	NYDEC-24 hr ½" RUNOFF	1.2	1-YR	200,812	2178	.605	3	65.1	14.3	70.1
	NYDEC-24 hr ½" RUNOFF	1.2	1-YR	200,812	2178	.605	5	66.7	14.3	71.5

CASE #	BASIN		STORM	VR	DISCHARGE RATE (Ω)		SHORT CIRC-UIT PARA-METER (n)	OVERALL AVG. DYNAMIC REMOVAL	OVERALL AVG. QUIE-SCENT REMOVAL	OVERALL AVG. TSS REMOVAL
	TYPE	STORAGE (acre-ft)		(ft^3)	(ft^3/hr)	(cfs)		(%)	(%)	(%)
6	NYDEC-40 hr ½" RUNOFF	1.2	1-YR	200,812	1306.8	.363	1	56.5	13.3	62.3
	NYDEC-40 hr ½" RUNOFF	1.2	1-YR	200,812	1306.8	.363	3	65.1	13.3	69.8
	NYDEC-40 hr ½" RUNOFF	1.2	2-YR	200,812	1306.8	.363	5	66.7	13.3	71.1

7.2 PLANT NUTRIENT AND HEAVY METAL REMOVAL

Of import to water quality maintenance is the removal of suspended plant nutrients, BOD, and heavy metals loadings from stormwater. The Northern Virginia Planning District Commission Study [13] summarizes findings on the percent of dissolved contaminates, those not associated with solids, in stormwater runoff for stabilized urban land use. These values are shown in Table 7.5 for commercial and industrial land use.

TABLE 7.5: PERCENTAGE OF PLANT NUTRIENT AND HEAVY METALS LOADS IN DISSOLVED FORMS FOR COMMERCIAL AND INDUSTRIAL LAND USE

PHOSPHORUS[a] (%)	NITROGEN[a] (%)	LEAD[b] (%)	ZINC[b] (%)	BOD (%)
41.6	68.1	13.2	55.5	52.0

[a]NOTE: Reported values for stabilized urban land uses are based on mean ratios of total loads. Reported values for transitional urban and rural - agricultural land uses are based on mean ratios of instantaneous concentrations.

[b]NOTE: Reported values are based on mean ratios of a number of instantaneous concentrations.

By using the values in table 7.5, the percent of the contaminants contained in the suspend portion of TSS can be calculated. The suspended portion of TSS can then be applied to the total percent removal of TSS to arrive at a removal percent for the plant nutrients and heavy metals. These values are calculated for both the project design and the alternate minimum NYDEC standard detention basins. The results are shown in table 7.6.

TABLE 7.6: % PLANT NUTRIENT AND HEAVY METAL LOADS REMOVED WITH SUSPENDED SOLIDS (n=3 for all cases)

CASE #	BASIN		OVER-ALL AVG. TSS REMOV-AL	POLLUTANT REMOVAL (%)				
	TYPE	STORAGE (acre-ft)	(%)	P	N	Pb	Zn	BOD
1	PROJECT	6.0	89.7	52.4	28.6	77.9	39.9	43.1
2	PROJECT 1 YR 24 HR STORM	4.61	86.8	50.7	27.7	75.3	38.6	41.7
3	NYDEC-24 hr 1 YR 24 HR STORM	4.61	86.8	50.7	27.7	75.3	38.6	41.7
4	NYDEC-40 hr 1 YR 24 HR STORM	4.61	86.5	50.5	27.6	75.1	38.5	41.5
5	NYDEC-24 hr ½"RUNOFF	1.2	70.1	40.9	22.4	60.8	31.2	33.6
6	NYDEC-40 hr ½"RUNOFF	1.2	69.8	40.8	22.3	60.6	31.1	33.5

8.0 DISCUSSION OF RESULTS

From the results outlined previously, it appears that an extended detention basin, designed to NYDEC guidelines, is effective in improving runoff water quality through the removal of suspended particulate pollutants.

It is, however, obvious, upon inspection of Table 7.4, that the driving factor in the overall removal of suspended pollutants is the available storage or the volume of the basin. Upon comparing case 3, the basin designed to the NYDEC guideline of providing enough volume for the 1-yr., 24 hour storm, to case 5, the basin designed to hold ½" of runoff from all impervious surfaces, there is an average difference in suspended sediment removal rates of 17.3%.

The percent plant nutrients and heavy metals removed is directly correlated to the overall percent removal of TSS. Since only the suspended portion of these contaminants will settle out with TSS, 100% removal will never be achieved due to the action of sedimentation only. However, again comparing the results of the 1-yr., 24 hour storm basin, case 3, versus the ½" runoff basin, case 5, the greater TSS removed results in a greater portion of plant nutrient and heavy metal contaminants removed.

Again, upon reviewing the results in Table 7.4, it becomes clear that the resulting TSS removal, due to a difference in theoretical detention times, is not significant in this instance. (Compare case 3 to 4 and case 5 to 6.) This can be explained, in part, by examining equations 7 and 9. Equation 7 calculates the effective volume (V_E) of the basin and is the only place where the discharge rate (Ω), which controls the detention time, enters into the computations. V_E is then used in equation 9 to calculate the percent removal of sediment via quiescent settling. Many other parameters are involved in these two equations, including basin volume (V_B) and rainfall statistics, which remain constant for the cases where only detention time is varied. Although detention time is a determining factor in suspended pollutant removal through quiescent settling, as shown in figure 5.5, for this case, it becomes apparent that this basin is operating in a narrow band of V_E/V_R.

Another reason for the similarity between these cases is that the volume of the basin (V_B) or storage volume should be altered along with the discharge rate in order to optimize the design. In this analysis, the volume of the basin remains the same in the cases where the detention times are varied.

9.0 CONCLUSIONS

Based on the analysis results presented, several conclusions can be made regarding the NYDEC guidelines for extended detention basins in term of water quality improvement in western and central New York. As discussed earlier, the NYDEC guidelines [12] are based on the study conducted by the Northern Virginia Planning District Commission [13 & 16] for the Metropolitan Washington Council of Governments. It is assumed, although not explicitly stated, that the NYDEC infers the same treatment level will be obtained for the western and central New York region as is obtained for the Metropolitan Washington D.C. region. The Washington study [13] projects an annual average pollutant removal rate for sediment of approximately 88%.

The project basin designed correctly to the NYDEC guidelines results in an overall average pollutant removal rate for sediment ranging from 81.6% to 87.7%, dependent on the short circuit parameter (n). It can, therefore, be concluded that approximately the same treatment level can be obtained for the western and central New York State region as was obtained for the Washington D.C. region and that extended detention basins designed to the NYDEC specifications will be effective at removing suspended pollutants.

Another conclusion is that the most important factor for effective particulate pollutant removal is the storage volume provided in the basin design. It is therefore important that the NYDEC guidelines be applied properly. If the storage volume is not designed based on the <u>larger</u> of runoff volume generated by the 1-yr., 24 hour storm or the volume generated by ½" of runoff from all impacted surfaces, much lower pollutant removal will be obtained. For this case, 17.3% less sediment is removed if the ½" runoff criteria is used instead of the 1-yr., 24 hour storm runoff volume.

It is also important to note the differences in the NYDEC [12] and Washington [13] guidelines with reference to detention time. The NYDEC states that the runoff must be detained for a minimum of 24 hours whereas the Washington Council states that the runoff must be detained for an <u>average</u> of 24 hours which equates to a brim-full drawdown time of 40 hours.[13] Although this did not have a profound impact on the resulting sediment removal rates for this study, it may, given different watershed and precipitation characteristics impact the outcome. It would, therefore, be in the best interest of the NYDEC to change the wording in their guidelines to indicate an <u>average</u> detention time if they have assumed the same level of treatment as the Washington D.C. area studies achieved.

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APPENDIX

MODEL COMPUTER CODE

```
      PROGRAM BASIN
C ***********************************************************
C *   Program written by:      Karlene R. Thomas            *
C *   Advisor:               Dr. F. Sciremammano            *
C *   In partial fullfillment of Thesis work                *
C *   Date written:            August, 1993                 *
C ***********************************************************
C *   This program uses a method developed in the document: *
C *   "Methodology for Analysis of Detention Basins for     *
C *   control of Urban Runoff Quality", EPA440/5-87-001,    *
C *   NITS PB87-116562, 1987.  The method employed in this  *
C *   program uses precipitation data, watershed character- *
C *   istics and detention basin dimensions and predicts the *
C *   removal of total suspended solids (TSS) and thus the  *
C *   resulting water quality.                              *
C ***********************************************************
C *   User Input:    A,CV,HB,WB,LB,SAB,VB,N                 *
C ***********************************************************
C *   Variables:                                            *
C *   V    Precipitation Volume Mean (in)                   *
C *   D    Precipitation Duration Mean (hr)                 *
C *   INTENS    Precipitation Intensity Mean (in/hr)        *
C *   DELTA     Precipitation Interval Mean (hr)            *
C *   CVQ  Coeff. of variation of Rainfall Intensity        *
C *   CVV  Coeff. of Variation of Rainfall Volume           *
C *   CVD  Coeff. of Variation of Rainfall Duration         *
C *   A    Watershed size (acres)                           *
C *   CV   Watershed runoff coefficient                     *
C *   HB   Avg. basin depth (ft)                            *
C *   WB   Avg. basin width (ft)                            *
C *   LB   Avg. basin length (ft)                           *
C *   SAB  Surface area of basin (ft^2)                     *
C *   VB   Storage volume of basin (ft^3)                   *
C *   QR   Runoff flow rate (ft^3/hr)                       *
C *   VR   Runoff volume (ft^3)                             *
C *   OVR  Overflow rate or avg. loading rate during        *
C *        mean storm (ft/hr)                               *
C *   PSV  Particle settling velocity matirx (ft/hr)        *
C *   RM   Removal at mean overflow rate matrix             *
C *   RL   Long term avg. removal (avg. fraction of total   *
C *        mass removed)                                    *
C *   R    Working variable (1/CVQ^2)                       *
C *   Z    Max. fraction removed at very low rates (Z=100)  *
C *   OARD Overall avg. dynamic removal (%)                 *
C *   OARQ Overall avg. quiescent removal (%)               *
C *   OAR  Overall avg. removal, entire basin (%)           *
C *   FD   Fraction sediment not removed (dynamic)          *
C *   FQ   Fraction sediment not removed (quiescent)        *
C *   COMB Combined % removal for each partical size        *
C *   VE   Effective volume (ft^3)                          *
C *   NPS  # of particle sizes                              *
```

```
C *   N     Parameter which provides a measure of the degree  *
C *         of turbulence or short circuiting                 *
C *   SUMRL      Sum of RL                                    *
C *   SUMREM     Sum of REM                                   *
C *   VEVR Ratio of VE/VR                                     *
C *   REM  %Removal of sediment under quiescent conditions    *
C *   COMB Combined % removal of sediment for part. size      *
C *   OMEGA      Solids removal rate for each particle size   *
C *                                                           *
C ************************************************************
C
      IMPLICIT NONE
C
C * Define the variables
C
      INTEGER I, Z, NPS
      PARAMETER (Z=100, NPS=5)
      REAL V,D,INTENS,DELTA,A,CV,HB,WB,LB,SAB,VB,QR,VR,CVQ,CVV,CVD
      REAL OVR,R,OAR,OARQ,OARD,VRATIO,E,VE,SUMRL,N,SUMREM,FD,FQ
      REAL PSV(NPS),RM(NPS),RL(NPS),OMEGA(NPS),VEVR(NPS),REM(NPS)
      REAL COMB(NPS), OHOLD
C
C ****NYS RAINFALL DATA, STATION ROCHESTER, NY #307167**********
C
      V = .22
      V = V/12
      INTENS = .034
      INTENS = INTENS/12
      DELTA = 60
      D = 7.1
      CVV=1.55
      CVQ = 1.51
      CVD=1.15
C
C ******************************
C * Get the user defined input
C
      PRINT *, 'ENTER THE WATERSHED SIZE (ACRES): '
      READ *, A
C
C * Convert acres to ft^2
C
      A = A*43560
C
      PRINT *,'ENTER THE RUNOFF COEFFICIENT OF THE WATERSHED (CV)'
      READ *, CV
      PRINT *, 'ENTER POND DIMENSIONS...'
      PRINT *, 'AVERAGE DEPTH (FT): '
      READ *, HB
      PRINT *, 'WIDTH (FT): '
      READ *, WB
```

```
      PRINT *, 'LENGTH (FT): '
      READ *, LB
C
      SAB = WB*LB
      VB = WB*LB*HB
C
C * Calculate runoff parameters
C
      QR = INTENS*CV*A
C
C * Give user option to enter volume rain runoff or have *
C * calculated *
C
      PRINT *, ' '
      PRINT *, 'ENTER VOLUME RUNOFF (VR) IF KNOWN IN FT^3...'
      PRINT *, 'IF NOT KNOWN, ENTER 0 AND PROGRAM WILL CALCULATE:'
      READ *, VR
      IF (VR .EQ. 0) VR = V*CV*A
C
C * Give user option to enter a discharge rate (omega) in ft^3/hr
C * if using this program to analyze detention pond. Omega will
C * be calculated if user enters 0 for use as a wet pond.
C

      PRINT *, ' '
      PRINT *, 'ENTER A DISCHARGE RATE (OMEGA) IN FT^3/HR IF
     +     ANALYZING A DETENTION POND.  IF  ANALYZING A WET POND
     +     ENTER 0 AND PROGRAM WILL CALCULATE OMEGA FOR YOU.'
C
      READ *, OHOLD
C
C * Removal under dynamic conditions
C  ---------------------------------
C * Calculate overflow rate
C
      OVR = QR/SAB
C
C * Set up particle settling velocity array
C
      PSV(1) = .03
      PSV(2) = .3
      PSV(3) = 1.5
      PSV(4) = 7.0
      PSV(5) = 65.0
C
C * Get user input for estimation of degree of turbulence
C * or short circuiting
C
      PRINT *,'(n) IS A PARAMETER WHICH PROVIDES A MEASURE OF THE
      PRINT *, 'DEGREE OF TURBULENCE AND SHORT CIRCUITING.'
      PRINT *, ' '
```

```
      PRINT *, 'ACCORDING TO THE FOLLOWING CRITERIA, PLEASE CHOOSE A
      PRINT *, 'VALUE WHICH BEST FITS YOUR APPLICATION. IF YOU ARE
      PRINT *, 'UNSURE CHOOSE n=1 FOR A CONSERVATIVE ESTIMATE.'
      PRINT *, ' '
      PRINT *, '     n = 1          VERY POOR PERFORMANCE'
      PRINT *, '     n = 3          GOOD'
      PRINT *, '     n = 5          VERY GOOD'
      PRINT *, 'ENTER n:'
      READ *, N
C
C
C * Set up output table
C
      PRINT *, ' '
      PRINT *, ' '
      PRINT *, ' '
      PRINT *, '     LONG TERM DYNAMIC REMOVAL'
      PRINT *, '_________________________________________'
      PRINT 20, 'SIZE','PARTICLE', '%RM','%RL'
      PRINT 30, 'FRACTION','SET. VEL.'
      PRINT *, '_________________________________________'
      PRINT *, ' '
20    FORMAT (1X,A9,A16,A7,A7)
30    FORMAT (1X,A11,A15)
C
      R=1/CVQ**2
      SUMRL = 0.
C
      DO 10 I=1,NPS
C
C * Calculate removal at the mean overflow rate for each size
C * fraction (eq.8)
C
           RM(I) = (1-((1 +((1/N)*(PSV(I)/OVR)))**(-N)))*100 C
C
C * Calculate the long term avg. removal or long term avg. fraction
C * of total mass removed (fig. 2, eq. 3)
C
           RL(I) = (Z*(R/(R-LOG(RM(I)/Z)))**(R+1))
           SUMRL = SUMRL + RL(I)
C
C * Print ongoing results in table
C
      PRINT 40, I, PSV(I), RM(I), RL(I)
C
40    FORMAT (1X,I7,F16.2,F9.1,F7.1)
C
10    CONTINUE
C
C * Calculate overall average removal rate
C
```

```
      OARD=SUMRL/NPS
C * Calculate fraction not removed
C
      FD=(100-OARD)/100
      PRINT *, ' '
      PRINT 11, 'OVERALL AVERAGE REMOVAL(DYNAMIC) = ', OARD, '%' C
11    FORMAT (1X,A36,F6.1,A1)
      PRINT *, ' '
      PRINT *, ' '
      PRINT *, ' '
C
C * Compute removal under quiescent conditions
C
C * Set up output table
C
C
      PRINT *, '      LONG TERM QUIESCENT REMOVAL'
      PRINT *, '__________________________________________________'
      PRINT 21, 'SIZE','PARTICLE', 'OMEGA','VE/VR','% REM'
      PRINT 31, 'FRACTION','SET. VEL.'
      PRINT *, '__________________________________________________'
      PRINT *, ' '
21    FORMAT (1X,A9,A16,A9,A9,A9)
31    FORMAT (1X,A11,A15)
C
C * Calculate Omega - solids removal rate or use entered discharge
C * rate
C
      DO 51 I=1,NPS
           IF (OHOLD .EQ. 0) THEN
                OMEGA(I)=PSV(I)*SAB
           ELSE
                OMEGA(I)=OHOLD
           ENDIF
C
C * Calculate effective volume (VE) - (Fig. 4)
C
           CALL VEFF(VB,DELTA,OMEGA(I),VR,VE)
C
           VEVR(I)=VE/VR
C
C * Calculate % Removal
C
           CALL LAGUERRE(CVV,CVQ,CVD,VEVR(I),REM(I))
C
           SUMREM=SUMREM+REM(I)
C
C * Print ongoing results for Quiescent conditions in table
C
           PRINT 41, I,PSV(I),OMEGA(I),VEVR(I),REM(I)
C
```

```
41        FORMAT(1X,I7,F16.2,F11.1,F9.2,F9.1)
C
51   CONTINUE
C
C * Calculate overall average removal rate
C
C
     OARQ=SUMREM/NPS
C
C * Calculate fraction not removed (quiescent)
C
     FQ=(100-OARQ)/100
C
     PRINT *, ' '
     PRINT 11, 'OVERALL AVERAGE REMOVAL(QUIESCENT) = ', OARQ,'%'
C
     PRINT *, ' '
     PRINT *, ' '
     PRINT *, ' '
C
C * Compute the combined removal under dynaminc and quiescent
C * conditions
C
     OAR = (1-(FQ*FD))*100
C
C * Set up summary table
C
C
     PRINT *, '     SUMMARY TABLE TSS REMOVAL'
     PRINT *,'______________________________________________________________________'
     PRINT 22, 'SIZE','PARTICLE', '%REMOVAL','%REMOVAL','% REMOVAL'
     PRINT 32,'FRACTION','SET.VEL.','DYNAMIC','QUIESCENT','COMBINED
     PRINT *,'______________________________________________________________________'
     PRINT *, ' '
22   FORMAT (1X,A9,A16,A12,A12,A12)
32   FORMAT (1X,A11,A14,A12,A12,A12)
C
C * Calculate values for summary table
C
     DO 60 I=1,NPS
          COMB(I)=(1-(((100-RL(I))/100)*((100-REM(I))/100)))*100
          PRINT 53, I, PSV(I),RL(I),REM(I),COMB(I)
60   CONTINUE
53   FORMAT (1X,I7,F16.2,F12.1,F12.1,F12.1)
C
     PRINT *, ' '
     PRINT *,'____________________________________________________________________'
     PRINT *, ' '
     PRINT 54, ' ','ALL',OARD,OARQ,OAR
54   FORMAT (1X,A7,A16,F12.1,F12.1,F12.1)
     PRINT *, ' '
```

```
C     PRINT 199, J, XR, ROOT
C
C   Calculate how close to specified tolerance the root is
C
      CALCTOL = ABS((XR-X2)/XR)
C
C   Compute next X
C
      IF (ROOT*ROOT1 .GT. 0.0) THEN
           ROOT1 = ROOT
           X1 = XR
           IF (ROOT*FSAVE .GT. 0.0) ROOT2=ROOT2/2.0
           FSAVE=ROOT
      ELSE
           ROOT2 = ROOT
           X2 = XR
           IF (ROOT*FSAVE .GT. 0.0) ROOT1=ROOT1/2.0
           FSAVE = ROOT
      END IF
C
      END DO
C
C   Specified tolerance has been met so print the results
C
C     PRINT 203, J, XR, ROOT
C
      VE=XR
C
C     PRINT *, ' '
C199 FORMAT ('AT ITERATION',I3, 3X,'X=', E14.7, 4X, ' F(X)=' E14.7)
C203 FORMAT (/' TOLERANCE MET IN ',I4,' ITERATIONS   X= ', E14.7,
C      +          ' F(X) = ',E14.7)
C
      END
C
C
C   *****************************************************************
C   Function EQUATE takes the given x value and calculates F(x)     *
C   according to the function programmed below.                    *
C   If the user would like to program a different function, simply*
C   change the "EQUATE=" line below.                                *
C   *****************************************************************
C
      FUNCTION EQUATE(VE,DELTA,OMEGA,VR,VB)
      REAL VE,DELTA,OMEGA,VR,VB,S
      EXTERNAL BESSK1
C
C
      CALL INTEGRATE(VE,VB,DELTA,OMEGA,VR,S)
C
      IF (VE.EQ.0) THEN
```

```
        EQUATE = 0
      ELSE
        EQUATE=(2*DELTA*OMEGA*(1-EXP(-VB/(DELTA*OMEGA)))*(VE/VR)**.5
     &             *BESSK1(2*(VE/VR)**.5)+(2/VR)*S)-VE
C     PRINT *, 'EQUATE=',EQUATE
C     PRINT *, 'S RETURNED=',S
      ENDIF
      RETURN
      END
C
C
      SUBROUTINE INTEGRATE(VE,VB,DELTA,OMEGA,VR,S)
C *****************************************************************
C * --INTEGRATE performs numerical integration using the Simpsons
C * rule. Returns as S the integral of the function FUNC from A to
C * B.  The parameters EPS can be set to the desired fractional
C * accuracy and JMAX so that 2^JMAX-1 is the max. allowed number
C * of steps.
C *****************************************************************
C
C
      REAL VE,VB,S,DELTA,OMEGA,VR
      EXTERNAL FUNC
C
C
      B=VE
      CALL QSIMP(FUNC,0,B,S,VB,DELTA,OMEGA,VR)
C
      RETURN
      END
C
      SUBROUTINE QSIMP(FUNC,A,B,S,VB,DELTA,OMEGA,VR)
C ****************************************************************
      PARAMETER (EPS=1.E-2, JMAX=20)
      OST=-1.E30
      OS= -1.E30
      DO 11 J=1,JMAX
           CALL TRAPZD(FUNC,A,B,ST,J,VB,DELTA,OMEGA,VR)
           S=(4.*ST-OST)/3.
           IF (ABS(S-OS).LT.EPS*ABS(OS)) RETURN
           OS=S
           OST=ST
11    CONTINUE
      PAUSE 'Too many steps.'
      END
C
C
      SUBROUTINE TRAPZD(FUNC,A,B,S,N,VB,DELTA,OMEGA,VR)
C ***********************************************************
      IF (N.EQ.1) THEN
           S=0.5*(B-A)*(FUNC(A,B,VB,DELTA,OMEGA,VR)+
```

```
     &              FUNC(B,B,VB,DELTA,OMEGA,VR))
          IT=1
     ELSE
          TNM=IT
          DEL=(B-A)/TNM
          X=A+2.0*DEL
          SUM=0.
          DO 11 J=1,IT
                    SUM=SUM+FUNC(X,B,VB,DELTA,OMEGA,VR)
                    X=X+DEL
11        CONTINUE
          S=0.5*(S+(B-A)*SUM/TNM)
          IT=2*IT
     ENDIF
     RETURN
     END
C
C
     REAL FUNCTION FUNC(X,VE,VB,DELTA,OMEGA,VR)
C ***************************************************************
     REAL X,VB,VE,DELTA,OMEGA,VR
     EXTERNAL BESSK0
C
     IF (X.EQ.0) THEN
      FUNC=0.0
     ELSE
      FUNC=(-(DELTA*OMEGA)*EXP(-(X+VB-VE)/(DELTA*OMEGA))
   &      -X+VE+(DELTA*OMEGA))*(BESSK0(2*(X/VR)**.5))
     ENDIF
     RETURN
     END
C
C
     FUNCTION BESSI0(X)
C ***************************************************************
     REAL*8 Y,P1,P2,P3,P4,P5,P6,P7,Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8,Q9
     DATA P1,P2,P3,P4,P5,P6,P7/1.0D0,3.5156229D0,3.0899424D0
    *     1.2067492D0, 0.2659732D0,0.360768D-1,0.45813D-2/
     DATA Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8,Q9/0.39894228D0,0.1328592D-1,
    *    0.225319D-2,-0.157565D-2,0.916281D-2,-0.2057706D-1,
    *    0.2635537D-1,-0.1647633D-1,0.392377D-2/
C
     IF (ABS(X).LT.3.75) THEN
          Y=(X/3.75)**2
          BESSI0=P1+Y*(P2+Y*(P3+Y*(P4+Y*(P5+Y*(P6+Y*P7)))))
     ELSE
          AX=ABS(X)
          Y=3.75/AX
          BESSI0=(EXP(AX)/SQRT(AX))*(Q1+Y*(Q2+Y*(Q3+Y*(Q4
     *                 +Y*(Q5+Y*(Q6+Y*(Q7+Y*(Q8+Y*Q9))))))))
     ENDIF
```

```
      RETURN
      END
C
      FUNCTION BESSI1(X)
C ****************************************************************
      REAL*8 Y,P1,P2,P3,P4,P5,P6,P7,
     *    Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8,Q9
      DATA P1,P2,P3,P4,P5,P6,P7/0.5D0,0.87890594D0,0.51498869D0,
     *    0.15084934D0,0.2658733D-1,0.301532D-2,0.32411D-3/
      DATA Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8,Q9/0.39894228D0,-0.3988024D-1,
     *    -0.362018D-2,0.163801D-2,-0.1031555D-1,0.2282967D-1,
     *    -0.2895312D-1,0.1787654D-1,-0.420059D-2/
      IF (ABS(X).LT.3.75) THEN
          Y=(X/3.75)**2
          BESSI1=X*(P1+Y*(P2+Y*(P3+Y*(P4+Y*(P5+Y*(P6+Y*P7))))))
      ELSE
          AX=ABS(X)
          Y=3.75/AX
          BESSI1=(EXP(AX)/SQRT(AX))*(Q1+Y*(Q2+Y*(Q3+Y*(Q4+
     *              Y*(Q5+Y*(Q6+Y*(Q7+Y*(Q8+Y*Q9))))))))
      ENDIF
      RETURN
      END
C
      FUNCTION BESSK0(X)
C ****************************************************************
      REAL*8 Y,P1,P2,P3,P4,P5,P6,P7,
     *    Q1,Q2,Q3,Q4,Q5,Q6,Q7
      DATA P1,P2,P3,P4,P5,P6,P7/-0.57721566D0,0.42278420D0,
     *    0.23069756D0, 0.3488590D-1,0.262698D-2,0.10750D-3,0.74D-5/
      DATA Q1,Q2,Q3,Q4,Q5,Q6,Q7/1.25331414D0,-0.7832358D-1,
     *    0.2189568D-1,-0.1062446D-1,0.587872D-2,-0.251540D-2,
     *    0.53208D-3/
C
      IF (X.LE.2.0) THEN
          Y=X*X/4.0
          BESSK0=(-LOG(X/2.0)*BESSI0(X))+(P1+Y*(P2+Y*(P3+
     *              Y*(P4+Y*(P5+Y*(P6+Y*P7))))))
      ELSE
          Y=(2.0/X)
          BESSK0=(EXP(-X)/SQRT(X))*(Q1+Y*(Q2+Y*(Q3+
     *              Y*(Q4+Y*(Q5+Y*(Q6+Y*Q7))))))
      ENDIF
      RETURN
      END
C
      FUNCTION BESSK1(X)
C ****************************************************************
      REAL*8 Y,P1,P2,P3,P4,P5,P6,P7,
     *    Q1,Q2,Q3,Q4,Q5,Q6,Q7
      DATA P1,P2,P3,P4,P5,P6,P7/1.0D0,0.15443144D0,-0.67278579D0,
```

```
     *    -0.18156897D0,-0.1919402D-1,-0.110404D-2,-0.4686D-4/
      DATA Q1,Q2,Q3,Q4,Q5,Q6,Q7/1.25331414D0,0.23498619D0,
    *    -0.3655620D-1,0.1504268D-1,-0.780353D-2,0.325614D-2,
   *     -0.68245D-3/
C
      IF (X.LE.2.0) THEN
           Y=X*X/4.0
           BESSK1=(LOG(X/2.0)*BESSI1(X))+(1.0/X)*(P1+Y*(P2+
     *                Y*(P3+Y*(P4+Y*(P5+Y*(P6+Y*P7))))))
      ELSE
           Y=2.0/X
           BESSK1=(EXP(-X)/SQRT(X))*(Q1+Y*(Q2+Y*(Q3+
     *               Y*(Q4+Y*(Q5+Y*(Q6+Y*Q7))))))
      ENDIF
      RETURN
      END
C
C
      SUBROUTINE LAGUERRE(CVV,CVQ,CVD,V,REM)
C ****************************************************************
C *     LAGUERRE calculates the equation for FV (fraction of     *
C * all volumes not captured by basin) which is a double         *
C * integral equation.  Method used is Laguerre quadrature to    *
C * approximate the integral with weighted polynomials.          *
C ****************************************************************
      INTEGER N, I, J, K
      PARAMETER (N=10)
      REAL R1, R2, V, GR1, GR2, XK(N), WK(N), CVV, CVQ, CVD
      REAL SUM1, SUM2, TOTAL1, TOTAL2, FV, REM,HOLDG,GAMMLN
      EXTERNAL GAMMLN
C
      XK(1) = .13779
      XK(2) = .72945
      XK(3) = 1.80834
      XK(4) = 3.40143
      XK(5) = 5.55249
      XK(6) = 8.33015
      XK(7) = 11.84378
      XK(8) = 16.27925
      XK(9) = 21.99658
      XK(10) = 29.92069
C
      WK(1) = 3.08441E-1
      WK(2) = 4.01119E-1
      WK(3) = 2.18068E-1
      WK(4) = 6.20874E-2
      WK(5) = 9.50151E-3
      WK(6) = 7.53008E-4
      WK(7) = 2.82592E-5
      WK(8) = 4.24931E-7
      WK(9) = 1.83956E-9
```

```
      WK(10) = 9.91182E-13
C
      R1 = 1/(CVQ**2)
      R2 = 1/(CVD**2)
C
C * Call function to calculate Gamma function
C
      HOLDG=GAMMLN(R1)
      GR1=EXP(HOLDG)
C
      HOLDG=GAMMLN(R2)
      GR2=EXP(HOLDG)
C
C     PRINT *, 'GAMMA OF CVV AND CVD=',GR1,GR2
C
C * Calculate %REM (Removal)
C
            TOTAL1=0
            TOTAL2=0
            DO 10 I=1, N
               SUM1 = WK(I)*((XK(I)/R1)**R1)*(1/R1)*EXP
     &            ((-R1)*R2*(V/XK(I)))
               TOTAL1 = TOTAL1 + SUM1
10          CONTINUE
C
            DO 20 I=1,N
            SUM2=WK(I)*(XK(I)/R2)*(1/R2)*(((XK(I)/R2)+
    &           ((R1*V)/XK(I)))**(R2-1))
            TOTAL2 = TOTAL2 + SUM2
20          CONTINUE
C
            FV=(((R1**R1)*(R2**R2))/(GR1*GR2))*TOTAL1*TOTAL2
C
            REM = (1-FV)*100
C
      RETURN
      END
C
C
      FUNCTION GAMMLN(XX)
C ******************************************************************
      REAL*8 COF(6),STP,HALF,ONE,FPF,X,TMP,SER,XX
      DATA COF,STP/76.18009173D0,-86.50532033D0,24.01409822D0,
&       -1.231739516D0,.120858003D-2,-.536382D-5,2.50662827465D0/
      DATA HALF,ONE,FPF/0.5D0,1.0D0,5.5D0/
      X=XX-ONE
      TMP=X+FPF
      TMP=(X+HALF)*LOG(TMP)-TMP
      SER=ONE
      DO 11 J=1,6
           X=X+ONE
```

```
          SER=SER+COF(J)/X
11    CONTINUE
      GAMMLN=TMP+LOG(STP*SER)
      RETURN
      END
```

MODEL COMPUTER RUNS FOR DIFFERENT CASES

CASE #1: PROJECT BASIN (n=3)

ENTER THE WATERSHED SIZE (ACRES):
43.2
ENTER THE RUNOFF COEFFICIENT OF THE WATERSHED (CV)
.69
ENTER POND DIMENSIONS...
AVERAGE DEPTH (FT):
4
WIDTH (FT):
154
LENGTH (FT):
450

ENTER VOLUME RUNOFF (VR) IF KNOWN IN FT^3...
IF NOT KNOWN, ENTER 0 AND PROGRAM WILL CALCULATE:
200812

ENTER A DISCHARGE RATE (OMEGA) IN FT^3/HR IF ANALYZING A DETENTION POND. IF ANALYZING A WET POND ENTER 0 AND PROGRAM WILL CALCULATE OMEGA FOR YOU.
8173.9

(n) IS A PARAMETER WHICH PROVIDES A MEASURE OF THE DEGREE OF TURBULENCE AND SHORT CIRCUITING.

ACCORDING TO THE FOLLOWING CRITERIA, PLEASE CHOOSE A VALUE WHICH BEST FITS YOUR APPLICATION. IF YOU ARE UNSURE, CHOOSE n=1 FOR A CONSERVATIVE ESTIMATE.

n = 1	VERY POOR PERFORMANCE
n = 3	GOOD
n = 5	VERY GOOD

ENTER n:
3

LONG TERM DYNAMIC REMOVAL

SIZE FRACTION	PARTICLE SET. VEL.	%RM	%RL
1	0.03	40.4	20.0
2	0.30	95.8	87.5
3	1.50	99.9	99.7
4	7.00	100.0	100.0
5	65.00	100.0	100.0

OVERALL AVERAGE REMOVAL(DYNAMIC) = 81.4%

LONG TERM QUIESCENT REMOVAL

SIZE FRACTION	PARTICLE SET. VEL.	OMEGA	VE/VR	% REM
1	0.03	8173.9	1.25	44.4
2	0.30	8173.9	1.25	44.4
3	1.50	8173.9	1.25	44.4
4	7.00	8173.9	1.25	44.4
5	65.00	8173.9	1.25	44.4

OVERALL AVERAGE REMOVAL(QUIESCENT) = 44.4%

SUMMARY TABLE TSS REMOVAL

SIZE FRACTION	PARTICLE SET.VEL.	%REMOVAL DYNAMIC	%REMOVAL QUIESCENT	% REMOVAL COMBINED
1	0.03	20.0	44.4	55.5
2	0.30	87.5	44.4	93.1
3	1.50	99.7	44.4	99.8
4	7.00	100.0	44.4	100.0
5	65.00	100.0	44.4	100.0
	ALL	81.4	44.4	89.7

TOTAL % REMOVAL OF TSS FOR THIS BASIN IS 89.7 %

CASE #2: PROJECT BASIN, 1 YR. 24 HR. STORM (n=3)

```
ENTER THE WATERSHED SIZE (ACRES):
43.2
ENTER THE RUNOFF COEFFICIENT OF THE WATERSHED (CV)
.69
ENTER POND DIMENSIONS...
AVERAGE DEPTH (FT):
4
WIDTH (FT):
125
LENGTH (FT):
402

ENTER VOLUME RUNOFF (VR) IF KNOWN IN FT^3...
IF NOT KNOWN, ENTER 0 AND PROGRAM WILL CALCULATE:
200812

ENTER A DISCHARGE RATE (OMEGA) IN FT^3/HR IF ANALYZING A
DETENTION POND.  IF ANALYZING A WET POND ENTER 0 AND PROGRAM
WILL CALCULATE OMEGA FOR YOU.
8173.9

(n) IS A PARAMETER WHICH PROVIDES A MEASURE OF THE DEGREE
OF TURBULENCE AND SHORT CIRCUITING.

ACCORDING TO THE FOLLOWING CRITERIA, PLEASE CHOOSE A VALUE
WHICH BEST FITS YOUR APPLICATION. IF YOU ARE UNSURE, CHOOSE
n=1 FOR A CONSERVATIVE ESTIMATE.

        n = 1           VERY POOR PERFORMANCE
        n = 3           GOOD
        n = 5           VERY GOOD
ENTER n:
3
```

LONG TERM DYNAMIC REMOVAL

SIZE FRACTION	PARTICLE SET. VEL.	RM	*RL
1	0.03	31.9	15.8
2	0.30	92.4	78.9
3	1.50	99.8	99.3
4	7.00	100.0	100.0
5	65.00	100.0	100.0

OVERALL AVERAGE REMOVAL(DYNAMIC) = 78.8%

LONG TERM QUIESCENT REMOVAL

SIZE FRACTION	PARTICLE SET. VEL.	OMEGA	VE/VR	% REM
1	0.03	8173.9	0.92	37.6
2	0.30	8173.9	0.92	37.6
3	1.50	8173.9	0.92	37.6
4	7.00	8173.9	0.92	37.6
5	65.00	8173.9	0.92	37.6

OVERALL AVERAGE REMOVAL(QUIESCENT) = 37.6%

SUMMARY TABLE TSS REMOVAL

SIZE FRACTION	PARTICLE SET.VEL.	%REMOVAL DYNAMIC	%REMOVAL QUIESCENT	% REMOVAL COMBINED
1	0.03	15.8	37.6	47.4
2	0.30	78.9	37.6	86.8
3	1.50	99.3	37.6	99.6
4	7.00	100.0	37.6	100.0
5	65.00	100.0	37.6	100.0
	ALL	78.8	37.6	86.8

TOTAL % REMOVAL OF TSS FOR THIS BASIN IS 86.8 %

CASE #3: NYDEC-24 HR DETENTION, 1 YR. 24 HR. STORM (n=3)

ENTER THE WATERSHED SIZE (ACRES):
43.2
ENTER THE RUNOFF COEFFICIENT OF THE WATERSHED (CV)
.69
ENTER POND DIMENSIONS...
AVERAGE DEPTH (FT):
4
WIDTH (FT):
125
LENGTH (FT):
402

ENTER VOLUME RUNOFF (VR) IF KNOWN IN FT^3...
IF NOT KNOWN, ENTER 0 AND PROGRAM WILL CALCULATE:
200812.4

ENTER A DISCHARGE RATE (OMEGA) IN FT^3/HR IF ANALYZING A DETENTION POND. IF ANALYZING A WET POND ENTER 0 AND PROGRAM WILL CALCULATE OMEGA FOR YOU.
8367.18

(n) IS A PARAMETER WHICH PROVIDES A MEASURE OF THE DEGREE OF TURBULENCE AND SHORT CIRCUITING.

ACCORDING TO THE FOLLOWING CRITERIA, PLEASE CHOOSE A VALUE WHICH BEST FITS YOUR APPLICATION. IF YOU ARE UNSURE, CHOOSE n=1 FOR A CONSERVATIVE ESTIMATE.

n = 1	VERY POOR PERFORMANCE
n = 3	GOOD
n = 5	VERY GOOD

ENTER n:
3

LONG TERM DYNAMIC REMOVAL

SIZE FRACTION	PARTICLE SET. VEL.	%RM	%RL
1	0.03	31.9	15.8
2	0.30	92.4	78.9
3	1.50	99.8	99.3
4	7.00	100.0	100.0
5	65.00	100.0	100.0

OVERALL AVERAGE REMOVAL(DYNAMIC) = 78.8%

LONG TERM QUIESCENT REMOVAL

SIZE FRACTION	PARTICLE SET. VEL.	OMEGA	VE/VR	% REM
1	0.03	8367.2	0.92	37.6
2	0.30	8367.2	0.92	37.6
3	1.50	8367.2	0.92	37.6
4	7.00	8367.2	0.92	37.6
5	65.00	8367.2	0.92	37.6

OVERALL AVERAGE REMOVAL(QUIESCENT) = 37.6%

SUMMARY TABLE TSS REMOVAL

SIZE FRACTION	PARTICLE SET.VEL.	%REMOVAL DYNAMIC	%REMOVAL QUIESCENT	% REMOVAL COMBINED
1	0.03	15.8	37.6	47.5
2	0.30	78.9	37.6	86.8
3	1.50	99.3	37.6	99.6
4	7.00	100.0	37.6	100.0
5	65.00	100.0	37.6	100.0
	ALL	78.8	37.6	86.8

TOTAL % REMOVAL OF TSS FOR THIS BASIN IS 86.8 %

CASE #4: NYDEC - 40 HR DETENTION, 1 YR. 24 HR. STORM (n=3)

ENTER THE WATERSHED SIZE (ACRES):
43.2
ENTER THE RUNOFF COEFFICIENT OF THE WATERSHED (CV)
.69
ENTER POND DIMENSIONS...
AVERAGE DEPTH (FT):
4
WIDTH (FT):
125
LENGTH (FT):
402

ENTER VOLUME RUNOFF (VR) IF KNOWN IN FT^3...
IF NOT KNOWN, ENTER 0 AND PROGRAM WILL CALCULATE:
200812.4

ENTER A DISCHARGE RATE (OMEGA) IN FT^3/HR IF ANALYZING A DETENTION POND. IF ANALYZING A WET POND ENTER 0 AND PROGRAM WILL CALCULATE OMEGA FOR YOU.
5020.31

(n) IS A PARAMETER WHICH PROVIDES A MEASURE OF THE DEGREE OF TURBULENCE AND SHORT CIRCUITING.

ACCORDING TO THE FOLLOWING CRITERIA, PLEASE CHOOSE A VALUE WHICH BEST FITS YOUR APPLICATION. IF YOU ARE UNSURE, CHOOSE n=1 FOR A CONSERVATIVE ESTIMATE.

n = 1	VERY POOR PERFORMANCE
n = 3	GOOD
n = 5	VERY GOOD

ENTER n:
3

LONG TERM DYNAMIC REMOVAL

SIZE FRACTION	PARTICLE SET. VEL.	%RM	%RL
1	0.03	31.9	15.8
2	0.30	92.4	78.9
3	1.50	99.8	99.3
4	7.00	100.0	100.0
5	65.00	100.0	100.0

OVERALL AVERAGE REMOVAL(DYNAMIC) = 78.8%

LONG TERM QUIESCENT REMOVAL

SIZE FRACTION	PARTICLE SET. VEL.	OMEGA	VE/VR	% REM
1	0.03	5020.3	0.87	36.4
2	0.30	5020.3	0.87	36.4
3	1.50	5020.3	0.87	36.4
4	7.00	5020.3	0.87	36.4
5	65.00	5020.3	0.87	36.4

OVERALL AVERAGE REMOVAL(QUIESCENT) = 36.4%

SUMMARY TABLE TSS REMOVAL

SIZE FRACTION	PARTICLE SET.VEL.	%REMOVAL DYNAMIC	%REMOVAL QUIESCENT	% REMOVAL COMBINED
1	0.03	15.8	36.4	46.5
2	0.30	78.9	36.4	86.6
3	1.50	99.3	36.4	99.6
4	7.00	100.0	36.4	100.0
5	65.00	100.0	36.4	100.0
	ALL	78.8	36.4	86.5

TOTAL % REMOVAL OF TSS FOR THIS BASIN IS 86.5 %

CASE # 5: NYDEC, 24 HR DETENTION, 1/2" RUNOFF, VR = 1 YR. 24 HR. STORM (n=3)

ENTER THE WATERSHED SIZE (ACRES):
43.2
ENTER THE RUNOFF COEFFICIENT OF THE WATERSHED (CV)
.69
ENTER POND DIMENSIONS...
AVERAGE DEPTH (FT):
4
WIDTH (FT):
87
LENGTH (FT):
150

ENTER VOLUME RUNOFF (VR) IF KNOWN IN FT^3...
IF NOT KNOWN, ENTER 0 AND PROGRAM WILL CALCULATE:
200812.4

ENTER A DISCHARGE RATE (OMEGA) IN FT^3/HR IF ANALYZING A DETENTION POND. IF ANALYZING A WET POND ENTER 0 AND PROGRAM WILL CALCULATE OMEGA FOR YOU.
2178

(n) IS A PARAMETER WHICH PROVIDES A MEASURE OF THE DEGREE OF TURBULENCE AND SHORT CIRCUITING.

ACCORDING TO THE FOLLOWING CRITERIA, PLEASE CHOOSE A VALUE WHICH BEST FITS YOUR APPLICATION. IF YOU ARE UNSURE, CHOOSE n=1 FOR A CONSERVATIVE ESTIMATE.

n = 1	VERY POOR PERFORMANCE
n = 3	GOOD
n = 5	VERY GOOD

ENTER n:
3

LONG TERM DYNAMIC REMOVAL

SIZE FRACTION	PARTICLE SET. VEL.	%RM	%RL
1	0.03	9.9	7.1
2	0.30	59.8	32.7
3	1.50	95.3	86.1
4	7.00	99.9	99.6
5	65.00	100.0	100.0

OVERALL AVERAGE REMOVAL(DYNAMIC) = 65.1%

LONG TERM QUIESCENT REMOVAL

SIZE FRACTION	PARTICLE SET. VEL.	OMEGA	VE/VR	% REM
1	0.03	2178.0	0.23	14.3
2	0.30	2178.0	0.23	14.3
3	1.50	2178.0	0.23	14.3
4	7.00	2178.0	0.23	14.3
5	65.00	2178.0	0.23	14.3

OVERALL AVERAGE REMOVAL(QUIESCENT) = 14.3%

SUMMARY TABLE TSS REMOVAL

SIZE FRACTION	PARTICLE SET.VEL.	%REMOVAL DYNAMIC	%REMOVAL QUIESCENT	% REMOVAL COMBINED
1	0.03	7.1	14.3	20.4
2	0.30	32.7	14.3	42.4
3	1.50	86.1	14.3	88.1
4	7.00	99.6	14.3	99.6
5	65.00	100.0	14.3	100.0
	ALL	65.1	14.3	70.1

TOTAL % REMOVAL OF TSS FOR THIS BASIN IS 70.1 %

CASE # 6: NYDEC, 40 HR DETENTION, 1/2" RUNOFF, VR = 1 YR. 24 HR. STORM (n=3)

ENTER THE WATERSHED SIZE (ACRES):
43.2
ENTER THE RUNOFF COEFFICIENT OF THE WATERSHED (CV)
.69
ENTER POND DIMENSIONS...
AVERAGE DEPTH (FT):
4
WIDTH (FT):
87
LENGTH (FT):
150

ENTER VOLUME RUNOFF (VR) IF KNOWN IN FT^3...
IF NOT KNOWN, ENTER 0 AND PROGRAM WILL CALCULATE:
200821.4

ENTER A DISCHARGE RATE (OMEGA) IN FT^3/HR IF ANALYZING A DETENTION POND. IF ANALYZING A WET POND ENTER 0 AND PROGRAM WILL CALCULATE OMEGA FOR YOU.
1306.8

(n) IS A PARAMETER WHICH PROVIDES A MEASURE OF THE DEGREE OF TURBULENCE AND SHORT CIRCUITING.

ACCORDING TO THE FOLLOWING CRITERIA, PLEASE CHOOSE A VALUE WHICH BEST FITS YOUR APPLICATION. IF YOU ARE UNSURE, CHOOSE n=1 FOR A CONSERVATIVE ESTIMATE.

n = 1	VERY POOR PERFORMANCE
n = 3	GOOD
n = 5	VERY GOOD

ENTER n:
3

LONG TERM DYNAMIC REMOVAL

SIZE FRACTION	PARTICLE SET. VEL.	%RM	%RL
1	0.03	9.9	7.1
2	0.30	59.8	32.7
3	1.50	95.3	86.1
4	7.00	99.9	99.6
5	65.00	100.0	100.0

OVERALL AVERAGE REMOVAL(DYNAMIC) = 65.1%

LONG TERM QUIESCENT REMOVAL

SIZE FRACTION	PARTICLE SET. VEL.	OMEGA	VE/VR	% REM
1	0.03	1306.8	0.21	13.3
2	0.30	1306.8	0.21	13.3
3	1.50	1306.8	0.21	13.3
4	7.00	1306.8	0.21	13.3
5	65.00	1306.8	0.21	13.3

OVERALL AVERAGE REMOVAL(QUIESCENT) = 13.3%

SUMMARY TABLE TSS REMOVAL

SIZE FRACTION	PARTICLE SET.VEL.	%REMOVAL DYNAMIC	%REMOVAL QUIESCENT	% REMOVAL COMBINED
1	0.03	7.1	13.3	19.5
2	0.30	32.7	13.3	41.7
3	1.50	86.1	13.3	88.0
4	7.00	99.6	13.3	99.6
5	65.00	100.0	13.3	100.0
	ALL	65.1	13.3	69.8

TOTAL % REMOVAL OF TSS FOR THIS BASIN IS 69.8 %

SAMPLE RAIN DATA LISTING

hp07167j.prn

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SYNOP OUTPUT FILE

*** SYNOPTIC RAINFALL ANALYSIS OPTIONS ***

Location: ROCHESTER, NY

Beginning year 50
Ending year 71
Interpolated inter-event times 3 10
Minimum rainfall volume 0.00
Calendar year analysis .... months 1 - 12

Event data not printed ....
Storm event summary not printed ....
Computed statistics ....
Statistics not computed from logarithms ......
Probability data not output ....

INTER-EVENT TIME = 7

NUMBER OF VALID METER READINGS PER MONTH

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
50	104	114	118	49	33	27	1	28	38	58	123	74
51	116	79	84	62	35	47	37	10	37	19	89	94
52	74	60	65	77	70	4	20	25	32	37	61	53
53	64	61	76	42	73	15	24	28	26	35	39	51
54	69	63	59	54	28	17	15	30	38	43	57	116
55	37	55	94	68	26	4	11	39	20	108	46	79
56	95	94	82	71	51	16	28	41	29	15	35	75
57	77	31	62	72	52	33	14	6	37	33	64	61
58	123	164	32	48	36	42	44	20	52	92	76	24
59	142	91	81	38	17	17	12	16	37	80	51	146
60	96	133	75	42	86	26	11	33	3	46	24	49
61	51	68	79	95	47	31	27	25	5	36	64	47
62	60	62	29	72	15	38	24	32	46	41	43	54
63	49	67	49	32	46	7	27	39	22	3	103	95
64	55	48	65	66	34	22	21	36	15	19	48	71
65	102	66	60	47	13	10	18	30	24	56	73	62
66	102	62	56	48	35	20	15	32	44	13	83	60
67	35	60	45	46	67	20	21	23	59	70	74	46
68	71	33	63	36	70	39	11	25	30	55	109	109
69	76	57	34	80	54	49	18	20	23	35	90	107
70	91	94	37	40	41	29	30	20	50	94	100	121
71	95	99	80	38	50	30	42	28	25	22	61	91

MONTH		NUMBER	TOTAL	MINIMUM	MAXIMUM	AVERAGE	COEF-VAR
1							
DURATION	(hrs)	313.	2926.00	1.00	50.00	9.35	1.03
INTENSITY	(in/hr)	313.	5.1462	0.0025	0.1700	0.0164	0.94
VOLUME	(in)	313.	51.08	0.01	1.94	0.16	1.50
DELTA	(hrs)	312.	17273.00	8.50	330.00	55.36	0.88
2							
DURATION	(hrs)	268.	2599.00	1.00	57.00	9.70	1.07
INTENSITY	(in/hr)	268.	4.7118	0.0029	0.0916	0.0176	0.88
VOLUME	(in)	268.	54.23	0.01	2.93	0.20	1.76
DELTA	(hrs)	268.	14704.50	8.50	286.00	54.87	0.77
3							
DURATION	(hrs)	273.	2369.00	1.00	60.00	8.68	1.11
INTENSITY	(in/hr)	273.	6.3190	0.0027	0.1857	0.0231	1.08
VOLUME	(in)	273.	57.18	0.01	2.16	0.21	1.43
DELTA	(hrs)	273.	16004.50	8.00	302.00	58.62	0.85
4							
DURATION	(hrs)	260.	1954.00	1.00	39.00	7.52	0.96
INTENSITY	(in/hr)	260.	7.5577	0.0033	0.1383	0.0291	0.86
VOLUME	(in)	260.	55.83	0.01	1.31	0.21	1.19
DELTA	(hrs)	260.	16012.00	8.50	377.50	61.58	0.93
5							
DURATION	(hrs)	222.	1633.00	1.00	50.00	7.36	1.06
INTENSITY	(in/hr)	222.	7.9822	0.0038	0.2000	0.0360	0.90
VOLUME	(in)	222.	56.18	0.01	1.99	0.25	1.23
DELTA	(hrs)	222.	15656.50	9.00	365.00	70.52	0.93
6							
DURATION	(hrs)	188.	916.00	1.00	34.00	4.87	1.08
INTENSITY	(in/hr)	188.	11.5148	0.0067	0.5700	0.0612	1.18
VOLUME	(in)	188.	55.38	0.01	2.86	0.29	1.48
DELTA	(hrs)	188.	15804.50	8.00	459.00	84.07	0.86
7							
DURATION	(hrs)	196.	877.00	1.00	33.00	4.47	1.03
INTENSITY	(in/hr)	196.	13.8160	0.0050	0.6250	0.0705	1.23
VOLUME	(in)	196.	52.31	0.01	2.25	0.27	1.26
DELTA	(hrs)	196.	15902.00	8.50	433.00	81.13	0.94
8							
DURATION	(hrs)	206.	1033.00	1.00	32.00	5.01	0.99
INTENSITY	(in/hr)	206.	15.9199	0.0029	0.9200	0.0773	1.37
VOLUME	(in)	206.	67.56	0.01	2.39	0.33	1.25
DELTA	(hrs)	206.	17064.50	8.50	801.50	82.84	1.07
9							
DURATION	(hrs)	205.	1195.00	1.00	33.00	5.83	1.03
INTENSITY	(in/hr)	205.	9.2481	0.0045	0.5300	0.0451	1.32
VOLUME	(in)	205.	49.32	0.01	2.22	0.24	1.43
DELTA	(hrs)	205.	15747.50	8.00	343.50	76.82	0.95
10							
DURATION	(hrs)	199.	1568.00	1.00	87.00	7.88	1.34
INTENSITY	(in/hr)	199.	6.2913	0.0038	0.1667	0.0316	0.96

VOLUME	(in)	199.	55.66	0.01	3.91	0.28	1.82
DELTA	(hrs)	199.	16311.00	8.00	575.50	81.96	1.02
11							
DURATION	(hrs)	288.	2382.00	1.00	69.00	8.27	1.11
INTENSITY	(in/hr)	288.	6.7687	0.0026	0.1633	0.0235	0.89
VOLUME	(in)	288.	63.71	0.01	2.30	0.22	1.53
DELTA	(hrs)	288.	16822.50	8.00	300.00	58.41	0.86
12							
DURATION	(hrs)	364.	2833.00	1.00	61.00	7.78	1.12
INTENSITY	(in/hr)	364.	6.0497	0.0025	0.1300	0.0166	0.88
VOLUME	(in)	364.	51.39	0.01	1.45	0.14	1.60
DELTA	(hrs)	364.	16462.00	8.50	295.50	45.23	0.83

SUMMARY OF RAINFALL STATISTICS BY MONTH

MONTH	DURATION (hrs)		INTENSITY (in/hr)		VOLUME (in)		DELTA (hrs)	
	AVG	COV	AVG	COV	AVG	COV	AVG	COV
1.	9.35	1.03	0.0164	0.94	0.16	1.50	55.36	0.88
2.	9.70	1.07	0.0176	0.88	0.20	1.76	54.87	0.77
3.	8.68	1.11	0.0231	1.08	0.21	1.43	58.62	0.85
4.	7.52	0.96	0.0291	0.86	0.21	1.19	61.58	0.93
5.	7.36	1.06	0.0360	0.90	0.25	1.23	70.52	0.93
6.	4.87	1.08	0.0612	1.18	0.29	1.48	84.07	0.86
7.	4.47	1.03	0.0705	1.23	0.27	1.26	81.13	0.94
8.	5.01	0.99	0.0773	1.37	0.33	1.25	82.84	1.07
9.	5.83	1.03	0.0451	1.32	0.24	1.43	76.82	0.95
10.	7.88	1.34	0.0316	0.96	0.28	1.82	81.96	1.02
11.	8.27	1.11	0.0235	0.89	0.22	1.53	58.41	0.86
12.	7.78	1.12	0.0166	0.88	0.14	1.60	45.23	0.83

RAINFALL STATISTICS BY YEAR

YEAR		NUMBER	TOTAL	MINIMUM	MAXIMUM	AVERAGE	COEF-VAR
50							
DURATION	(hrs)	135.	1213.00	1.00	53.00	8.99	1.12
INTENSITY	(in/hr)	135.	3.6931	0.0029	0.2043	0.0274	1.05
VOLUME	(in)	135.	37.01	0.01	2.93	0.27	1.81
DELTA	(hrs)	134.	8643.00	8.50	801.50	64.50	1.34
51							
DURATION	(hrs)	155.	1204.00	1.00	43.00	7.77	1.01
INTENSITY	(in/hr)	155.	4.5516	0.0025	0.2600	0.0294	1.19
VOLUME	(in)	155.	36.21	0.01	1.62	0.23	1.38
DELTA	(hrs)	155.	8973.00	8.50	373.00	57.89	1.01
52							
DURATION	(hrs)	121.	931.00	1.00	52.00	7.69	1.20
INTENSITY	(in/hr)	121.	3.5280	0.0033	0.2750	0.0292	1.29
VOLUME	(in)	121.	27.14	0.01	1.31	0.22	1.38
DELTA	(hrs)	121.	8764.50	8.50	318.00	72.43	0.90
53							
DURATION	(hrs)	130.	898.00	1.00	51.00	6.91	1.14
INTENSITY	(in/hr)	130.	5.1400	0.0038	0.5300	0.0395	1.60

VOLUME	(in)	130.	30.38	0.01	1.85	0.23	1.51
DELTA	(hrs)	130.	8818.50	9.00	376.00	67.83	0.99
54							
DURATION	(hrs)	143.	1017.00	1.00	39.00	7.11	1.10
INTENSITY	(in/hr)	143.	4.8378	0.0027	0.2233	0.0338	1.19
VOLUME	(in)	143.	31.96	0.01	1.50	0.22	1.41
DELTA	(hrs)	143.	8736.00	8.50	309.00	61.09	0.86
55							
DURATION	(hrs)	129.	921.00	1.00	87.00	7.14	1.39
INTENSITY	(in/hr)	129.	5.3818	0.0025	0.6600	0.0417	1.83
VOLUME	(in)	129.	32.03	0.01	3.91	0.25	1.87
DELTA	(hrs)	129.	8834.50	8.00	355.50	68.48	0.94
56							
DURATION	(hrs)	155.	1119.00	1.00	34.00	7.22	0.96
INTENSITY	(in/hr)	155.	5.6935	0.0027	0.3300	0.0367	1.34
VOLUME	(in)	155.	34.41	0.01	1.20	0.22	1.25
DELTA	(hrs)	155.	8814.00	8.00	384.50	56.86	0.94
57							
DURATION	(hrs)	134.	905.00	1.00	40.00	6.75	1.14
INTENSITY	(in/hr)	134.	5.0808	0.0036	0.4400	0.0379	1.67
VOLUME	(in)	134.	25.66	0.01	1.99	0.19	1.52
DELTA	(hrs)	134.	8721.50	9.00	400.00	65.09	1.00
58							
DURATION	(hrs)	141.	1164.00	1.00	60.00	8.26	1.26
INTENSITY	(in/hr)	141.	5.1708	0.0038	0.5600	0.0367	1.63
VOLUME	(in)	141.	35.80	0.01	2.48	0.25	1.44
DELTA	(hrs)	141.	8682.50	10.00	272.50	61.58	0.88
59							
DURATION	(hrs)	129.	1094.00	1.00	61.00	8.48	1.27
INTENSITY	(in/hr)	129.	4.2451	0.0029	0.2250	0.0329	1.18
VOLUME	(in)	129.	32.23	0.01	2.88	0.25	1.55
DELTA	(hrs)	129.	9051.00	8.50	451.50	70.16	1.00
60							
DURATION	(hrs)	137.	970.00	1.00	47.00	7.08	1.13
INTENSITY	(in/hr)	137.	4.4064	0.0031	0.2800	0.0322	1.43
VOLUME	(in)	137.	26.76	0.01	2.07	0.20	1.60
DELTA	(hrs)	137.	8778.50	8.00	354.00	64.08	0.93
61							
DURATION	(hrs)	130.	996.00	1.00	43.00	7.66	1.09
INTENSITY	(in/hr)	130.	5.4003	0.0038	0.5700	0.0415	1.76
VOLUME	(in)	130.	30.51	0.01	1.86	0.23	1.29
DELTA	(hrs)	130.	8724.50	8.00	286.00	67.11	0.86
62							
DURATION	(hrs)	123.	860.00	1.00	33.00	6.99	0.91
INTENSITY	(in/hr)	123.	4.1983	0.0029	0.3000	0.0341	1.12
VOLUME	(in)	123.	29.25	0.01	2.22	0.24	1.48
DELTA	(hrs)	123.	8961.00	8.50	365.00	72.85	0.93
63							
DURATION	(hrs)	123.	873.00	1.00	47.00	7.10	1.12
INTENSITY	(in/hr)	123.	3.9852	0.0029	0.2400	0.0324	1.19
VOLUME	(in)	123.	24.09	0.01	1.66	0.20	1.43

DELTA	(hrs)	123.	8732.00	8.50	575.50	70.99	1.12
64							
DURATION	(hrs)	127.	867.00	1.00	36.00	6.83	1.04
INTENSITY	(in/hr)	127.	3.6539	0.0040	0.1200	0.0288	0.96
VOLUME	(in)	127.	22.45	0.01	1.41	0.18	1.37
DELTA	(hrs)	127.	8844.50	9.00	343.50	69.64	0.86
65							
DURATION	(hrs)	128.	941.00	1.00	50.00	7.35	1.22
INTENSITY	(in/hr)	128.	3.8365	0.0029	0.1700	0.0300	0.97
VOLUME	(in)	128.	25.16	0.01	1.42	0.20	1.38
DELTA	(hrs)	128.	8894.50	10.00	348.50	69.49	0.83
66							
DURATION	(hrs)	132.	951.00	1.00	36.00	7.20	0.95
INTENSITY	(in/hr)	132.	3.5482	0.0033	0.1900	0.0269	1.13
VOLUME	(in)	132.	26.11	0.01	1.94	0.20	1.63
DELTA	(hrs)	132.	8721.00	8.50	459.00	66.07	1.08
67							
DURATION	(hrs)	146.	892.00	1.00	50.00	6.11	1.27
INTENSITY	(in/hr)	146.	5.4381	0.0029	0.9200	0.0372	2.18
VOLUME	(in)	146.	29.84	0.01	1.99	0.20	1.62
DELTA	(hrs)	146.	8908.50	9.00	389.50	61.02	0.91
68							
DURATION	(hrs)	138.	1063.00	1.00	32.00	7.70	0.94
INTENSITY	(in/hr)	138.	4.6290	0.0025	0.3414	0.0335	1.39
VOLUME	(in)	138.	31.75	0.01	2.39	0.23	1.43
DELTA	(hrs)	138.	8728.00	8.00	262.50	63.25	0.88
69							
DURATION	(hrs)	128.	1042.00	1.00	44.00	8.14	1.08
INTENSITY	(in/hr)	128.	3.8959	0.0026	0.2000	0.0304	1.04
VOLUME	(in)	128.	29.14	0.01	1.30	0.23	1.29
DELTA	(hrs)	128.	8854.00	9.00	301.00	69.17	0.89
70							
DURATION	(hrs)	157.	1240.00	1.00	69.00	7.90	1.32
INTENSITY	(in/hr)	157.	6.1271	0.0033	0.6250	0.0390	1.73
VOLUME	(in)	157.	37.78	0.01	1.77	0.24	1.44
DELTA	(hrs)	157.	8720.00	8.00	369.00	55.54	0.94
71							
DURATION	(hrs)	141.	1124.00	1.00	48.00	7.97	0.99
INTENSITY	(in/hr)	141.	4.8840	0.0025	0.3167	0.0346	1.41
VOLUME	(in)	141.	34.16	0.01	2.25	0.24	1.61
DELTA	(hrs)	141.	8859.50	9.50	277.00	62.83	0.88

SUMMARY OF RAINFALL STATISTICS BY YEAR

YEAR	DURATION (hrs)		INTENSITY (in/hr)		VOLUME (in)		DELTA (hrs)	
	AVG	COV	AVG	COV	AVG	COV	AVG	COV
50.	8.99	1.12	0.0274	1.05	0.27	1.81	64.50	1.34
51.	7.77	1.01	0.0294	1.19	0.23	1.38	57.89	1.01
52.	7.69	1.20	0.0292	1.29	0.22	1.38	72.43	0.90
53.	6.91	1.14	0.0395	1.60	0.23	1.51	67.83	0.99
54.	7.11	1.10	0.0338	1.19	0.22	1.41	61.09	0.86

55.	7.14	1.39	0.0417	1.83	0.25	1.87	68.48	0.94
56.	7.22	0.96	0.0367	1.34	0.22	1.25	56.86	0.94
57.	6.75	1.14	0.0379	1.67	0.19	1.52	65.09	1.00
58.	8.26	1.26	0.0367	1.63	0.25	1.44	61.58	0.88
59.	8.48	1.27	0.0329	1.18	0.25	1.55	70.16	1.00
60.	7.08	1.13	0.0322	1.43	0.20	1.60	64.08	0.93
61.	7.66	1.09	0.0415	1.76	0.23	1.29	67.11	0.86
62.	6.99	0.91	0.0341	1.12	0.24	1.48	72.85	0.93
63.	7.10	1.12	0.0324	1.19	0.20	1.43	70.99	1.12
64.	6.83	1.04	0.0288	0.96	0.18	1.37	69.64	0.86
65.	7.35	1.22	0.0300	0.97	0.20	1.38	69.49	0.83
66.	7.20	0.95	0.0269	1.13	0.20	1.63	66.07	1.08
67.	6.11	1.27	0.0372	2.18	0.20	1.62	61.02	0.91
68.	7.70	0.94	0.0335	1.39	0.23	1.43	63.25	0.88
69.	8.14	1.08	0.0304	1.04	0.23	1.29	69.17	0.89
70.	7.90	1.32	0.0390	1.73	0.24	1.44	55.54	0.94
71.	7.97	0.99	0.0346	1.41	0.24	1.61	62.83	0.88

RAINFALL STATISTICS BY STORM

STORM		NUMBER	TOTAL	MINIMUM	MAXIMUM	AVERAGE	COEF-VAR
DURATION	(hrs)	2982.	22285.00	1.00	87.00	7.47	1.13
INTENSITY	(in/hr)	2982.	101.3251	0.0025	0.9200	0.0340	1.50
VOLUME	(in)	2982.	669.85	0.01	3.91	0.22	1.51
DELTA	(hrs)	2981.	193764.50	8.00	801.50	65.00	0.96

ANNUAL STATISTICS

NUMBER OF STORMS	22	2982.	121.	157.	136.	0.08
ANNUAL VOLUMES (in)	22	669.85	22.45	37.78	30.45	0.14

"ANNUAL AVERAGE" EVENT STATISTICS

DURATION	(hrs)	22	164.35	6.11	8.99	7.47	0.09
INTENSITY	(in/hr)	22	0.7459	0.0269	0.0417	0.0339	0.13
VOLUME	(in)	22	4.93	0.18	0.27	0.22	0.11
DELTA	(hrs)	22	1437.97	55.54	72.85	65.36	0.08

CORRELATION MATRIX OF STORM VARIABLES

	DURATION	INTENSITY	VOLUME	DELTA
DURATION	1.000	-0.068	0.626	0.099
INTENSITY	-0.068	1.000	0.443	0.123
VOLUME	0.626	0.443	1.000	0.173
DELTA	0.099	0.123	0.173	1.000

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